Summer 8-15-2017

Understanding Household, Network, and Organizational Drivers of Adoption of Cleaner Cooking Fuels in Rural India

Praveen Kumar
Washington University in St. Louis

WASHINGTON UNIVERSITY IN ST. LOUIS

BROWN SCHOOL

Dissertation Examination Committee:

Gautam Yadama, Co-chair
Ross C. Brownson, Co-chair
Jenine Harris
Sumi Mehta
Shanta Pandey
Ken Schechtman
Jean-Francois Trani

Understanding Household, Network, and Organizational Drivers of Adoption of Cleaner Cooking Fuels in Rural India

By
Praveen Kumar

A dissertation presented to
The Graduate School
of Washington University in
partial fulfillment of the
requirements for the degree
of Doctor of Philosophy

August 2017
St. Louis, Missouri

Table of Contents

List of Figures

List of Tables

Acknowledgements

Countless individuals provided their unflinching support and invaluable encouragement during my journey in this doctoral program and as I complete this dissertation. I want to start by thanking my parents to be as caring as ever. My ambition of pursuing a PhD became their aspiration of seeing me "holding" a PhD. This process would have never witnessed fruition without their confidence in me. In fact, whatever little I might have accomplished in life that would never have been possible without their hard work and sacrifice. My siblings Anita, Manoj, and Renu, my brother-in-law Shantanu, my sister-in-law Shruti, my nieces Ishita and Kaavya, and my nephew Vedant- my family who were there for me whenever I needed. My brother and my sister-in-law have been with me through thick and thin before and during my doctoral training. My brother at times paid for my college tuition in India, he lent his motorbike, which I ended using "forever" till I came to the US, and he paid for all my university applications in the US. My sister and my brother-in-law were always very curious of my well-being, and have taken care of all my needs here in the US. These are just a few of the numerous instances, which demonstrate how central I am for them when I need them the most. My doctoral journey would have been far less fun without my frequent trips to their places in Mumbai and in Princeton.

I owe a special thanks to my mentor and co-chair, Gautam Yadama. It has been a true privilege to learn from him. I will remain grateful to him forever for numerous opportunities that he provided. It was he who believed in me, was instrumental in bringing me to the Brown School, supported and nurtured my research pursuits throughout my doctoral training, and would quell my sporadic work related anxieties. He has not only served as a guide in my doctoral training but has also helped me evolve as overall a better professional. I am grateful to have learnt so much from him, and I look forward to continued collaboration with Gautam. I also want to thank Shanta Pandey for her consistent support and care. She has been the go-to person for all my queries on

personal and professional front. I have to include here that just like many in the Brown School, I would always be grateful for what this amazing couple, Shanta and Gautam has done for my well-being since I have been here in the US.

I want to take this opportunity to thank the members of my dissertation committee- Gautam Yadama, Ross Brownson, Shanta Pandey, Jenine Harris, Sumi Mehta, Jean-Francois Trani, and Ken Schechtman, for their willingness to share their expertise to support this study, and for their commitment to promote high quality scholarship. I had a wonderful opportunity as a summer fellow with the Global Alliance for Clean Cookstoves at the UN Foundation, where I thoroughly enjoyed working with my supervisor Sumi Mehta. I owe her special thanks for her guidance and for helping me cultivate key connections in this sector. I look forward to collaborating and working with her as I advance my research career.

I also want to offer my gratitude to several faculties at Brown School and from other departments at Washington University, who helped me shape my research. I am especially thankful to Eddie Lawlor, Renee Cunningham-Williams, Michael Sherraden, Joseph Steensma, Pratim Biswas, and Mario Castro. Our program managers, first Lucinda Cobb and then Marissa Hardwrict always willingly helped me with all the administrative requisites so that I can focus on my research.

Support from McDonnell International Scholars Academy deserves a special mention. A fully funded scholarship was the most what a PhD student could have asked for! But the Academy has been much more than that. It helped me, as a McDonnell scholar, to make friends from diverse cultures, to cultivate networks, and to develop my overall interpersonal skills. I hold deep regards for Jim Wertsch, Kristine Williams, Angie Rahaman, and Carla Koberna.

I have been fortunate to call so many amazing people in my life as friends. They have been both a source of motivation and inspiration to me. Doctoral training is a taxing endeavor. I feel that with my amazing bunch of friends, this entire journey was more of a fun filled learning experience.

Some of these friends deserve a special mention – Aastha, Nishesh, Rita, Shannon, Vithya, Ericka, Allison, Harry, Yiqi, Aytakin, Sameer, Neeraj, Manjari, Prachi, Divya, Gaurav, Swasti, Ayush, Nilendu, Chetan, and Sandeep.

During the phase of writing my dissertation, I met with an amazing person and friend, Geetika. In such a short span of 2-3 months with her, who would imagine that I would learn so much about the real meaning of the "pursuit of happiness"! We have had countless discussions (and arguments!) on the true purpose of life, indulged in sporadic disagreements on multiple issues including the content of my thesis, and on our corresponding areas of work. Still, my well-being during this process of dissertation writing has been central to her daily life for the past few months. I feel that that these disagreements on multiple issues somehow expanded my critical thinking. I must thank her for supporting me during this time of writing my dissertation.

I can't imagine concluding my round of gratitude if I do not mention our field implementing partner, Foundation of Ecological Security, and its team members Kaushal, Hemalatha, Geetha, Noorjan, and Shaheensha. Their tireless effort on timely completion of quality data collection, willingness to accommodate urgent but last-minute modifications in field work, timely data upload, and assistance in data analyses ensured that I have all the necessary components to complete this document on time. In addition, I would also like to thank Ethan Dover, our research assistant at Wash U for helping me with the data cleaning and initial analysis.

Finally, none of this work would have been possible without a generous research funding support. I am grateful to have received funding for this study as part of a larger grant provided by the Clean Cooking Implementation Science Network (ISN). The network was launched by the NIH in partnership with USAID, CDC, and the Global Alliance for Clean Cookstoves (UN Foundation). I would also like to acknowledge research and training opportunities provided by Washington University Institute of Clinical and Translational Sciences grant UL1TR000448 from the National

Center for Advancing Translational Sciences (NCATS) of the NIH, and also by the National Institute of Environmental Health Sciences grant R21ES021585-01.

MANY THANKS TO ALL OF YOU!

Praveen Kumar

Washington University in St. Louis

August 2017

Dedicated to

My MOM and DAD

Abstract of the dissertation

Understanding Household, Network, and Organizational Drivers of Adoption of Cleaner Cooking Fuels in Rural India

By

Praveen Kumar

Doctor of Philosophy in Social Work

Washington University in St. Louis, 2017

Professor Gautam Yadama, Co-chair

Professor Ross C. Brownson, Co-chair

Adoption of evidence-based cleaner cooking systems such as Liquefied Petroleum Gas (LPG) is a crucial first step in eventually providing a sustainable solution for household air pollution. To promote adoption of LPG in below poverty line households, we require evidence-based implementation strategies. For these strategies to be feasible and scalable, they need to be grounded in a thorough understanding of the household, network, and organizational level drivers of LPG adoption. However, systematic research on adoption of LPG by poor communities is still lacking.

The overall objective of the study was to develop a better understanding about new insights on the reach of LPG among the poor in rural India. The study used a RE-AIM Implementation Science framework to develop a better understanding about the reach of LPG among the poor in rural India, and examined the factors that influence adoption of LPG in below poverty line households of rural India. The design was a case control study. The study used multistage random sampling technique to first select rural habitations and then households from these habitations for data collection. The study had two specific aims: 1) to understand how rural LPG adopters vary from other rural households on factors of affordability, accessibility, and awareness of LPG; and 2) to evaluate the relative influence of gender based personal networks on LPG adoption in these rural households.

The aims were accomplished through a set of semi-structured questionnaire and standardized personal gender based network surveys in below poverty line households of rural India.

The study found that multiple factors pertaining to affordability, accessibility, and awareness concurrently impact adoption of LPG in rural households. The results also showed that personal gender based networks of women and men impact LPG adoption. Both women and men respondents from the LPG adopter households had significantly higher gender based homophily and significantly higher homophily in LPG adoption, when they were compared to that of women and men respondents from the non-LPG adopter households. Men respondents from the LPG adopter households had relatively higher structural holes, when compared to that of men respondents from the non-LPG adopter households. Despite a few limitations, the study has strong implications for policy and practice, and provides multiple avenues for continued research.

I. Specific Aims

1.0 Organization of this chapter

This chapter is divided in four sections. Section 1.1 reflects on social, environmental and public health challenges in vulnerable communities of the world due to traditional cooking practices. This section highlights the shortcoming of adoption and use of improved biomass[1] cookstoves, and importance of a near complete transition to cleaner cooking fuels such as Liquefied Petroleum Gas (LPG). Taking LPG as a cleaner cooking representative technology, and the case of India, section 1.2 discusses the existing research gap. This section emphasizes the significance of understanding factors pertaining to affordability, accessibility, and awareness as determinants of adoption and sustained use of cleaner cooking fuels (LPG). Section 1.3 builds on section 1.2. This section highlights the overall research question of this study, delineates the two lines of inquiry of this study, and their corresponding hypotheses. Section 1.4 provides concluding remarks for this chapter.

1.1 Introduction

The UN commitment to achieving 17 goals by 2030 includes "access to affordable, reliable, sustainable, and modern energy for all" (global goal 7) (UN, 2015b). This goal recognizes the pressing issue of household air pollution (HAP), which impacts almost 41% of the global (and mostly poor) population, who continue to rely on solid biomass fuels such as fuelwood, crop residues, dung, and charcoal for heating and cooking (GACC, 2011). Owing to poor combustion efficiency, these solid fuels release aerosol emissions and particulate matters. They are a major source of HAP. These emissions have detrimental impact on health, climate, and environment. Approximately 4.3 million annual premature deaths are attributed to HAP exposure (WHO, 2014a). Nearly 50% deaths from acute lower respiratory infection among children below 5 years in underdeveloped countries are attributed to exposure to HAP (WHO, 2014a). Continuous exposure

[1] Biomass fuels are organic materials commonly used in rural areas. Instance of biomass fuels include fuelwood, crop residues, twigs, dung cake.

to these emissions also leads to pregnancy complications and stunted growth of children (WHO, 2014a). Unsustainable collection of biomass contributes to anthropogenic degradation of forests (El Tayeb Muneer & Mukhtar Mohamed, 2003; Yadama, 2013b). The gender division of labor dictates that in most societies women shoulder the primary responsibility of collecting biomass (Cecelski, 2000). Drudgery and time spent in collecting biomass deters the poor (especially women) from engaging in income generating activities. Harmful impacts of HAP on environment, public health, and economic well-being (especially of women) thus present a complex challenge.

Adoption and sustained use of cleaner cooking technologies such as cleaner biomass stoves or cleaner fuels (Liquefied Petroleum Gas [LPG], solar cookstoves, or induction stoves) are recommended as solutions to address the challenge of HAP. Dissemination and implementation (D&I) in clean cooking sector has most recently focused on cleaner biomass stoves (Slaski & Thurber, 2009a; Kirk R. Smith & Sagar, 2014). Strategies to disseminate and implement these cleaner biomass stoves among poor communities are problematic for four reasons:

1. A supra-linear nature of the HAP exposure-response curve suggests that expected health benefits of clean cooking can be attained only at very low levels of exposure (Burnett et al., 2014; Kirk R. Smith et al., 2014). For substantial health benefits from clean cooking, the World Health Organization (WHO) recommends reduction in $PM_{2.5}$ emission levels to at least 35 $\mu g/m^3$ (J. J. Lewis et al., 2017; WHO, 2014c). This is the annual mean interim target 1 for indoor air quality. Most of the ICS have poor performance against the WHO's recommended indoor air quality (IAQ) standards in the actual household scenario. Emissions performance of multiple models of ICS against the ISO's International Workshop Agreement's (IWA) tiers have shown that none of these stoves could be placed in tier 4 in terms of emissions performance. They are mostly placed in tier 1 and tier 2. Health related benefits are thus compromised despite switching

to cleaner biomass stoves. There has been a recent emphasis to develop strategies to push IWA's tier 4 cooking systems in energy poor communities.

2. Communities have to continue to perpetually depend on biomass as a cooking fuel to use cleaner biomass stove. These stoves do not offer a sustainable solution in terms of anthropogenic degradation of forests (Kirk R. Smith & Sagar, 2014).
3. Drudgery of collecting biomass and associated physical injuries (such as burns while cooking or bodily injuries due to carrying heavy biomass) continue to pose complex health and economic challenges.
4. Most of the cleaner biomass stoves have poor performance in terms of robustness and mechanical wear and tear.

Thus, despite some promise offered by these cleaner biomass stoves, health and environmental benefits continue to be substantially compromised. It is now recognized that while efforts are required to develop standards of cleaner stoves, more emphasis is needed to deploy cleaner cooking systems such as LPG (see Figure 1 and Figure 2). In rural poor communities of multiple geographies, transition to LPG has been saddled with numerous impediments. These impediments prevent substantial dividends on public health or environmental benefits. Evidence shows that a ubiquitous and free availability of biomass in rural interiors prevent a complete switch to LPG. High cost of refill sometimes beyond the affordability limits, lack of accessibility to LPG distribution centers, and lack of adequate awareness exacerbates this issue. Adoption, sustained, and a near exclusive use of LPG are crucial for reaping health and environmental benefits of cleaner cooking.

The overall objective of the current study was to derive new insights on the reach of LPG among the poor in rural India, and factors that influence adoption of LPG in below poverty line (BPL) households of rural India. The study had two specific lines of inquiry:

Aim 1: To understand how rural LPG adopters vary from other rural households on factors of affordability, accessibility, and awareness of LPG *(aim 1: adoption)*

Aim 2: To evaluate the relative influence of gender based personal networks on LPG adoption in rural households *(aim 2: personal network analysis)*

New efforts are underway to develop strategies to foster adoption and sustained use of LPG among poor communities. There is an increasing emphasis on LPG use among the poor. Adoption, sustained, and a near exclusive use of LPG by households could lead to achieving the expected WHO IAQ guidelines. Thus, adoption and sustained use of cleaner cooking fuels such as LPG by poor communities are proposed as solutions to address the issue of HAP (Lewis & Pattanayak, 2012; Ruiz-Mercado, Masera, Zamora, & Smith, 2011; Kirk R. Smith & Sagar, 2014; Yadama, 2013b; Yadama, Peipert, Sahu, Biswas, & Dyda, 2012). However, there has been inadequate attention to developing systematic research on adoption and sustained use of LPG by poor communities (Lucon, Coelho, & Goldemberg, 2004; Slaski & Thurber, 2009a; Kirk R. Smith & Sagar, 2014). Evidence base on strategies fostering adoption and sustained use of LPG among poor communities is weak.

Figure 1: Use of LPG cylinder and stoves in households (IndianExpress, 2011)

Figure 2: Transportation of LPG cylinders to households (Livemint, 2016)

Available literature on LPG adoption and use by poor communities can be broadly analyzed from supply and demand side perspectives:

1. Supply of LPG for poor households

Studies on LPG from the supply point of view have mostly focused on subsidies, pro-poor financing techniques, and low cost supply chain to increase affordability of poor households for LPG adoption and use. LPG, a clean and modern household fuel, is a petroleum product and its price is mostly governed by fluctuations in international markets. Nevertheless, it continues to outpace increase in income of poor communities (Venkataraman, Sagar, Habib, Lam, & Smith, 2010). Blanket fuel subsidies provided by governments of the underdeveloped countries such as India reduce direct costs of acquiring LPG for households. However, it has not proved to be efficacious as a policy instrument for poor communities. Poor households account for only a small part of total LPG fuel adoption and use as compared to their wealthy counterparts (Lucon et al., 2004; Kirk R. Smith & Sagar, 2014; Tripathi, Sagar, & Smith, 2015). Supply of higher rung of fuel such as LPG to billions of poor communities requires high level policy initiatives. It involves meticulous trade negotiations and mechanisms of differential subsidy systems (Kirk R. Smith &

Sagar, 2014; Tripathi et al., 2015). Streamlining subsidies on LPG to benefit poor communities is a gradual process (Masera, Saatkamp, & Kammen, 2000) involving multiple stakeholders (petroleum companies, petroleum rich nations, government policies on subsidies etc.) with (sometimes) conflicting interests (Venkataraman et al., 2010). It may also require an overhauling of energy policy at a higher order (Shrimali, Slaski, Thurber, & Zerriffi, 2011).

Large scale studies on the supply of LPG are significant to address the challenge. Streamlining of subsidies, low cost supply chain mechanisms, and pro-poor financing techniques have the potential to make LPG more affordable for the poor households (Venkataraman et al., 2010). However, even if an enabling supply-side climate is attained by the government, uptake and sustained use of LPG will remain a distant goal if there is a limited demand from poor communities. Kirk R. Smith and Sagar (2014) and Slaski and Thurber (2009a) argue that commensurate demand may expedite both rationalization of subsidies and revamp of energy policy for poor communities. Stronger evidence base on how to stimulate LPG demand among poor is needed (Damte & Koch, 2011; Ganesan & Vishnu, 2014; Lucon et al., 2004; Shrimali et al., 2011; Kirk R. Smith & Sagar, 2014)

2. Demand of LPG by poor households

There are limited studies focusing on analyzing the demand of LPG by poor households. There has been a lot of attention on exploring causality between affordability of households and adoption of LPG. For instance, the majority of empirical literature on adoption of cleaner cooking systems (including LPG) has three variables in common in its analyses: 1) household size; 2) income; and 3) fuelwood price (Lewis & Pattanayak, 2012). The relationship between income and adoption is moderated by social class, gender, acquisition barriers, and ethnicity. Female-headed households with higher incomes are more likely to adopt cleaner cooking technologies (Lewis & Pattanayak, 2012). In patriarchal societies even if the households have higher income, they are less likely to

adopt LPG (El Tayeb Muneer & Mukhtar Mohamed, 2003). Households belonging to marginalized groups, lower castes, lower social class, or indigenous groups are less likely to adopt LPG (Lewis & Pattanayak, 2012). This may be due to particular intrinsic value integrated with the use of traditional practices.

Findings on the impact of fuelwood price on adoption and sustained use of LPG are varied. Yadama et al. (2012) argue that there is a reduced propensity to shift to cleaner technologies if households have greater access to free fuelwood. Viswanathan and Kavi Kumar (2005), Edwards and Langpap (2005), and Heltberg (2005) argue that attaining a minimum threshold of household income is required for completely switching to cleaner cooking systems like LPG. Review of existing literature shows limited evidence based research on both adoption and sustained use of LPG. Studies on adoption are significant in exploring determinants which impact initial uptake of LPG (Lewis & Pattanayak, 2012). Adoption indicates presence of an LPG stove in a household (not necessarily in use) (GACC, 2015, 2016). Sustained use indicates the degree to which LPG is used and is integrated in daily behavior of users (GACC, 2015, 2016). Sustained users who exclusively use LPG are characterized by a complete switch to LPG, and with no intention of reverting to traditional stoves or traditional fuels (GACC, 2016). On the other hand, stackers combine LPG use with traditional stove use (GACC, 2015). Analysis of the demand side of LPG necessitates a study on both adoption and sustained use of LPG.

1.2 Research gap

Existing literature on adoption and sustained use of LPG by poor communities has three key limitations: 1) LPG is not the primary fuel in majority of the poor communities. Stacking with traditional cooking technologies is common, which limits expected health and environmental dividends (Ruiz-Mercado et al., 2011). Limited systematic studies are available to explore this challenge of stacking; 2) successful cases of those poor households who have sustainably used LPG

are needed. These cases can then be adapted and tailored for other poor communities; 3) there is considerable attention on understanding the impact of affordability on LPG adoption and use. From the supply side, governments provide subsidies and introduce pro-poor LPG schemes to reduce the overall LPG cost for uptake and use. From the demand side, as the household income increases, they tend to take up cleaner fuels like LPG. Increase in affordability to purchase LPG may drive uptake and sustained use. Lewis et al. (2015) argue that even if the acquisition barriers (like upfront cost) are waived to make cleaner technologies more affordable, sustained and exclusive use is low. Increase in affordability, thus, is a significant however, an inadequate driver.

Limited accessibility and awareness restrains communities to adopt and sustainably use LPG (Jain, Agrawal, & Ganesan, 2014; Pine et al., 2011; Slaski & Thurber, 2009a). Underdeveloped infrastructure critical to support LPG demand and supply, and free availability of biomass are underexplored accessibility related characteristics that merit greater attention. Similarly, targeted dissemination strategies including awareness campaigns in rural communities by the government or private players are critical to enhance uptake of LPG.

One of the reasons identified for the awareness gap is a lack of effective dissemination of relevant information to the people who can apply it through channels they use. Essentially taking a passive "*if you build it, they will come"* approach to dissemination does not work. Acemoglu, Ozdaglar, and Yildiz (2011), Choi, Kim, and Lee (2010), and E. M. Rogers (1983) argue that one of the key factors within the realm of awareness dissemination, which merits systematic study is personal networks of potential adopters of any social or technological innovation. Personal networks of users reveal the likelihood of which community members might have a greater propensity to adopt an innovation. Exchange of information in personal networks is a common occurrence. E. M. Rogers, Medina, Mario, and Wiley (2005) opine that structure and composition of personal networks determine the level of information dissemination. Thus, personal networks of users impact the level

of awareness of users. This, consequently impacts the potential choice of adoption or abandonment of an innovation. Awareness could be a function of the existing network ties of communities (Luke, 2012). Systematic examination of personal networks, thus, is central to analyses on awareness of users, which could impact adoption of technological innovation such as cleaner cooking systems.

To synthesize, commensurate emphasis has not been deployed to explore challenges of accessibility and awareness, which could also act as a deterrent of adoption and sustained use (El Tayeb Muneer & Mukhtar Mohamed, 2003; Pine et al., 2011; Slaski & Thurber, 2009a). Limited evidence base, thus, is available to explore combined issues of affordability, accessibility, and awareness (3As) to explore the challenge of adoption and sustained use of LPG by poor communities. Unless we systematically explore the 3As, which influence poor communities to adopt and sustainably use LPG, the UN's global goal 7 on affordable and clean energy will remain a challenge.

1.3 Research questions and hypothesis

This dissertation research is nested within a larger study on adoption and sustained use of LPG in resource poor settings in rural India, funded by the Clean Cooking Implementation Science Network (ISN), launched by the NIH, in partnership with USAID, the CDC, and the Global Alliance for Clean Cookstoves (United Nations Foundation). The ISN advances the science of uptake, sustained and a near exclusive use of cleaner cooking technologies in the developing world. The ISN is hosted by the Center for Global Health Studies at the Fogarty International Center, and supported by the NIH Common Fund.

This was a quantitative case control study (Song & Chung, 2010). **The overall goal of this study was to derive new insights on the reach of LPG among the poor in rural India, factors that influence adoption (initial uptake) of LPG in below poverty households (BPL) of rural India.** Both adoption and sustained use of LPG are crucial for addressing household air pollution.

This dissertation study as part of the ISN grant was confined to focus only on determinants of adoption of LPG. Exploring determinants of sustained use of LPG will succeed this dissertation, but is beyond the scope of the current study. The current study had following two specific lines of inquiry:

Aim 1: To understand how rural LPG adopters vary from other rural households on factors of affordability, accessibility, and awareness of LPG *(aim 1: adoption)*

Following hypotheses were tested for aim 1:

H1a: General[2] caste households are more likely to adopt LPG than households that belong to other caste group households (OBCs, and SC/STs) and religious minorities.

H1b: Households whose respondents (women) have a higher income are more likely to adopt LPG compared to households with respondents with lower income.

H1c: Households whose respondents are members of self-help groups (SHG) are more likely to adopt LPG compared to the households whose respondents are not members of any self-help group.

H1d: Households with higher gross income are more likely to adopt LPG than the households with lower gross income.

H1e: Households with higher land holdings are more likely to adopt LPG than the households with lower land holdings.

[2] **General caste:** Also called open category has no reservation in employment in the central or state government systems. It mainly comprises of three classes in the Varna system, which are the Brahmins, Kshatriyas and Vaishyas. **Scheduled tribes (STs):** These are tribes that have traditionally lived in the forests. They have traditionally been marginalized and not in the mainstream of the society. They are also known as Adivasis, hence called scheduled tribes as they have been added under a "schedule" of the constitution of India. **Scheduled Castes (SCs):** An economically and socially backward community, they have also been traditionally marginalized. **Other Backward castes or OBCs:** They also form a large group that is heterogeneous and has been considered by the constitution of India as being economically and socially backward. OBCs, SCs, and STs are provided with reservation in the central and also in state government systems to increase their representation in the mainstream society and to simultaneously improve their economic and social well-being.

H1f: Households with higher agricultural debt are more likely to adopt LPG than the households with lower agricultural debt.

H1g: Increase in the distance to tarmac roads from the household reduces the likelihood of that household to adopt LPG.

H1h: Increase in the distance to LPG distribution centers from the household reduces the likelihood of that household to adopt LPG.

H1i: There is a lower likelihood to adopt LPG in households where the respondents prefer smaller LPG cylinders over the larger cylinders in circulation.

H1j: There is a lower likelihood of household adoption of LPG when the respondents feel that biomass is easily available.

H1k: Increase in the distance to the source of biomass from the households increases the likelihood of those households to adopt LPG.

H1l: There is a higher likelihood of those households to adopt LPG, whose respondents (women) are involved in decision making to purchase new stoves.

H1m: There is a lower likelihood for households to adopt LPG, when respondents feel that LPG cylinders are unsafe.

H1n: There is a lower likelihood of households to adopt LPG when respondents feel that LPG is incompatible with traditional cooking practices.

H1o: Respondents are more likely to adopt LPG, when it enhances the social status of their households in their respective communities.

H1p: Those households where respondents have attended at least one in-person awareness campaign on LPG adoption are more likely to adopt LPG than households where respondents have not attended any in-person awareness campaign on LPG adoption.

Aim 2: To evaluate the relative influence of gender based personal networks on LPG adoption in rural households *(aim 2: personal network analysis)*

Following hypotheses were tested for aim 2:

H2a: Personal networks of women in LPG adopter households have higher structural holes than that of women in non-LPG adopter households.

H2b: Personal networks of men in LPG adopter households have higher structural holes than that of men in non-LPG adopter households.

H2c: Personal networks of women in LPG adopter households have higher gender based homophily than that of women in non-LPG adopter households.

H2d: Personal networks of men in LPG adopter households have higher gender based homophily than that of men in non-LPG adopter households.

H2e: Personal networks of women in LPG adopter households have higher caste based homophily than that of women in non-LPG adopter households.

H2f: Personal networks of men in LPG adopter households have higher caste based homophily than that of men in non-LPG adopter households.

H2g: Personal networks of women in LPG adopter households have higher homophily in LPG adoption than that of women in non-LPG adopter households.

H2h: Personal networks of men in LPG adopter households have higher homophily in LPG adoption than that of men in non-LPG adopter households.

This was a case control study using a multistage random sampling strategy. The outcome of interest for the case control study was the adoption of LPG. Case households were those who had adopted LPG. These households also had traditional stoves. They might be cooking in both types of stoves (stacking). The degree of use of LPG stoves and traditional stoves in these households might vary. Control households were those who had not adopted LPG, and exclusively cooked on

traditional stoves. The study sites were the habitations of two blocks *(mandals)* namely Thambalpalle and Peddamandyam in Chittoor district of Andhra Pradesh (AP) (see study location maps as Appendix 1). A sample size of 255 households was selected each for case and for control groups. Aim 1 relied on structured interviews with the primary cook (women) of the households selected for the study. These structured interviews were administered to all 510 (255 case + 255 control) households. Aim 2 relied on personal network survey instruments especially designed for conducting ego network surveys, and were administered to women (primary respondent) and men (spouse of primary respondent/primary male decision maker/senior most male member) of the household. A sample size of 100 LPG adopter households and 100 non-LPG adopter households were selected to administer personal network surveys to both women and men of each of these households.

1.4 Concluding remarks

This chapter introduced the challenge of HAP. Adoption and sustained use of cleaner cooking systems such as LPG is needed to address this challenge. Strategies to disseminate and implement LPG in poor communities will not be a success unless a strong evidence base is developed around the economic and social imperatives of LPG technologies in these poor communities. The overall aim and research questions attempt to build the evidence by exploring key factors of affordability, accessibility, and awareness among rural communities, which impact LPG adoption in these households. The next chapter discusses energy poverty, HAP, and significance of using cleaner cooking systems like LPG for public health, environment, and rural well-being. Since the study was conducted in India, a section in the next chapter briefly discusses the issue of HAP, and status of LPG adoption and sustained use in rural India.

II. Background and Significance

2.0 Organization of this chapter

This chapter elucidates in detail the background and significance of undertaking this study. The chapter is organized as follows. Section 2.1 and section 2.2 discuss the overall concept of energy poverty, health implications of HAP, and multiple government and non-government interventions to address this challenge. Taking LPG as a case for representative cleaner cooking technology, section 2.3 details the importance of adoption and sustained use of LPG for cooking, and lingering challenges associated with the adoption and use of cleaner biomass stoves among vulnerable poor communities. This study was placed in rural India. Section 2.4 discusses the existing scenario of adoption and use of LPG in rural India. This section also highlights the potential role of affordability, accessibility, and awareness related factors and the significance to empirically test these factors as enablers of adoption and sustained use of LPG in rural India. Section 2.5 provides concluding remarks for this chapter.

2.1 Introduction

The WHO report estimates severe health risks for close to 3 billion people across the world due to HAP (WHO, 2014a, 2014b). Burning of solid and lower rung of fuels in traditional stoves releases significant fine particulate matter including carbonaceous aerosol emissions. They are a prime source of HAP (Barnes, Openshaw, Smith, Van der Plas, & Mundial, 1994; S. Pachauri, Mueller, Kemmler, & Spreng, 2004; Ruiz-Mercado, Canuz, Walker, & Smith, 2013; Ruiz-Mercado et al., 2011; Kirk R. Smith et al., 2014; Kirk R Smith & Mehta, 2003). While the use of these traditional technologies and lower rung of fuels has detrimental health and environmental implications, in many areas of the world it is still the primary source of cooking and heating. Lack of adequate, high quality, modern, and affordable forms of energy or energy systems constitute energy poverty (S. Pachauri et al., 2004; Yadama, 2013b).

2.2 Energy Poverty

The International Energy Agency (IEA) defines energy poverty as lack of access to modern energy services. These services are household access to electricity and cleaner cooking facilities such as LPG and modern stoves. Energy poverty can also be defined as the lack of access and choice to adequate, affordable, reliable, high-quality, safe, and environmentally benign energy services to support economic and human development (Bonjour et al., 2013; GACC, 2011; Martin, Glass, Balbus, & Collins, 2011; S. Pachauri et al., 2004; Sagar, 2005). Around 3 billion people burn solid biomass for cooking and heating in traditional cookstoves (GACC, 2011). Also, around 1.6 billion people in the world do not have access to electricity and use dirty fuel like kerosene in wick lamps and traditional lanterns (Kanagawa & Nakata, 2008). Systematic research and evidence has shown that the use of these traditional technologies (wick lamps, petromax, lanterns, and traditional cookstoves) and use of lower rung of fuels (wood, charcoal, agricultural residues, animal dung, and kerosene) for cooking, heating, and lighting has pernicious health, environment, and climate impacts (Kanagawa & Nakata, 2008; Shrimali et al., 2011). These traditional energy systems have poor combustion efficiency. They release significant carbonaceous aerosol emissions and particulate matter contributing to HAP, and causing acute and chronic respiratory infection (Bonjour et al., 2013). Particularly, poor women and children are at a high risk of exposure to biomass smoke and adverse health outcomes (Martin et al., 2011). For instance, around 50% of deaths from ALRI among children under five years old in underdeveloped countries are attributed to HAP. WHO estimates 4.3 million deaths globally in 2012 alone due to HAP and almost all of them occurred in Low and Middle Income Countries (WHO, 2014a). In India for instance, HAP impacts over 145 million rural poor households (GIZ, 2014) and has been responsible for around 900,000 deaths annually (Brauer et al., 2016). Evidence suggests that black carbon released from the burning of these fuels in traditional technologies also expedites the melting of glacial ice contributing to global

climate change and disruption of monsoon. Continued reliance on forests for cooking fuels has resulted in a decline in the availability of biomass (Cecelski, 2000). This has added to the already existing burden of those who is responsible to collect them. The collection of biomass is primarily the responsibility of women through the gender division of labor (Cecelski, 2000). Decline in access to biomass fuel results in a persistent issue of higher time taken in cooking related activities. More time spent in cooking precludes the poor (especially women) from contributing in income generating activities and eventually perpetuating their economic misery (Cecelski, 2000). Lives of these communities are mired within the vicious loop of energy poverty and income poverty. This acts as a significant barrier to shifting to higher rung of fuels or cleaner energy technologies (Masera et al., 2000).

Although the United Nations' Millennium Development Goals (MDG) established in 2000 were devoid of any specific energy related objectives, energy was widely recognized as an important driver for achieving the goals for human development. Energy Poverty was also central to numerous international conventions including the Johannesburg's World Summit on Sustainable Development in 2002 and the United Nations Conference on Sustainable Development in 2012. The UN Sustainable Energy for All (SE4All), Global Alliance for Clean Cook stoves (GACC), Solar Cookers International, Lighting Africa and the International Solar Energy Society (ISES) are global concerted initiatives to tackle energy poverty. The UN declared 2012 as the 'International Year of Sustainable Energy for All'. The decade 2014-2024 has been declared as the 'UN decade of Sustainable Energy for All'. With the launch of the UN Sustainable Development Goals, energy poverty is now one of the global goals. In addition, detrimental impact of this challenge has been emphasized in other global goals too. It is widely accepted that addressing energy poverty will also lubricate accomplishment of other global goals. Thus, the sustainable development goals recognizes the issue of energy poverty and HAP in its global goal 7, which is "access to affordable, reliable, sustainable,

and modern energy for all" (UN, 2015b). Addressing energy poverty is central to the realization of this goal, and is significant for achieving the SDG 2030 target of "ensuring universal access to affordable, reliable and modern energy services" (UN, 2015b). In addition, addressing energy poverty is linked to achieving other multiple SDGs too.

There have been country level interventions by respective governments to tackle the challenge of energy poverty. The Government of India launched the National Biomass Cookstoves Initiative in 2009 with a commitment to distribute around 160 million cleaner biomass stoves to the rural poor households. China and Kenya also launched their respective cleaner biomass stove dissemination programs. The National Improved Stoves Program (NISP) of China and Kenya Ceramic Jiko (KCJ) charcoal stove dissemination of Kenya are some of the biggest cleaner cookstoves dissemination programs of the world (Shrimali et al., 2011). Recent but scattered endeavors of few countries like Brazil and India also include dissemination and implementation of LPG in these resource poor communities (Lucon et al., 2004; Sagar, 2005; Kirk R. Smith & Sagar, 2014; Tripathi et al., 2015). These large scale commitments and interventions are commendable. They may seem promising to tackle the challenge. However, merely a one-stroke dissemination of cleaner cooking technologies and fuels by governments or international organizations is a strategy, which witnessed failure in the past and in multiple countries (Shrimali et al., 2011). For instance, the government led clean energy interventions have been ineffective because of poor technology, misunderstanding community needs, structure of energy subsidies, coordination failures, and poor distribution networks despite large investments in these interventions (Shrimali et al., 2011; Venkataraman et al., 2010; Yadama, 2013b). Similarly, the charity driven NGOs encounter issues of effort fragmentation and insufficient attention to financial sustainability despite possessing strong understanding of community needs (Venkataraman et al., 2010). The solution incorporates far more nuanced understanding on the

demand side (energy poor communities), on the supply side (suppliers of energy systems), and on the policy side (enabling environment for addressing energy poverty).

2.3 Significance of adoption and sustained use of LPG in addressing Energy Poverty

Cleaner cooking systems such as cleaner biomass cookstoves, electric induction stoves, and LPG can replace the traditional cookstoves, and they demonstrate potential to address the challenges of energy poverty. Most of the recent efforts have mostly focused on the dissemination of cleaner biomass stoves in these communities. Use of cleaner biomass stoves are saddled with the following issues:

1. **Inadequately 'clean':** The exposure-response curve of HAP is supra-linear (Burnett et al., 2014; Kirk R. Smith & Sagar, 2014). This means that the expected respiratory health benefits can be attained only when the exposure levels are extremely low (Kirk R. Smith & Sagar, 2014). Extremely few cleaner biomass stoves pass the WHO IAQ standards (Kirk R. Smith & Sagar, 2014). The cleaner biomass stoves may relatively reduce the exposure to biomass pollutants compared to their performance with traditional cookstoves. However, they are inadequately clean to provide substantive health benefits to the users (Kirk R. Smith & Sagar, 2014).
2. **Reliance on biomass:** Cleaner biomass stoves perpetuate dependence on biomass. Environmental degradation has been another significant implication of relying on biomass for cooking. Energy poor households mostly have free availability of biomass from the nearby forests. With the uptake and use of cleaner biomass stoves, communities continue to degrade forests by their unrestrained and unsustainable harvest of biomass for cooking.
3. **Gender issues:** In most societies, women shoulder the responsibility of collecting biomass from these forests. Scattered evidence shows that women have been victims of sexual assault in these isolated areas of forests while collecting biomass (Cecelski, 2000). Carrying heavy

loads of biomass to long distances lead to physical injuries (Yadama, 2013b). Collection of biomass involves long hours, which deters rural women to engage in any income generation activities. Challenges in terms of women's safety, physical injuries, and time persist even if energy poor communities switch to these cleaner biomass stoves.

Addressing energy poverty is difficult if a cooking technology such as cleaner biomass stoves renders insufficient solution to health, environment, and gender issues. Recent national and international attention has therefore shifted to dissemination and implementation of LPG in such resource poor communities (Lucon et al., 2004; Kirk R. Smith & Sagar, 2014; Tripathi et al., 2015). LPG meets the WHO IAQ standards, and provides the expected health benefits (Kirk R. Smith & Sagar, 2014). Use of LPG does not require households to continue to rely on biomass. Low and middle income countries like Brazil has already initiated and India is currently planning to overhaul their subsidy systems, introduce pro-poor financial schemes, and bolster infrastructure so as to increase adoption and use of LPG in the rural landscape (Jain et al., 2014; Lucon et al., 2004; Kirk R. Smith & Sagar, 2014; Tripathi et al., 2015). Policy initiatives to improve LPG availability for poor communities are important. Despite such initiatives, demand side issues of adoption, sustained, and exclusive use of LPG by these communities remain (Jain et al., 2014; Kirk R. Smith & Sagar, 2014). Uptake and sustained use of LPG is a function of economic and social determinants, which have not been systematically studied so far (Lewis & Pattanayak, 2012; Yadama, 2013b). Energy-society relationship is intricate. Vulnerability of energy poor population exacerbates the intricacies of this relationship. Evidence base on strategies fostering uptake and sustained use of LPG among energy poor communities is weak and anecdotal. Unless we explore the economic and social determinants of adoption and sustained use of LPG, larger policy level initiatives on pro-poor LPG dissemination will not render adequate success to address energy poverty (Lewis & Pattanayak, 2012; Ruiz-

Mercado et al., 2011; Kirk R. Smith & Sagar, 2014; Tripathi et al., 2015; Yadama, 2013b; Yadama et al., 2012).

2.4 LPG for poor: case of rural India

Domestic consumption of LPG in India has witnessed gradual increase over the past few decades (see Figure 3). In recent years, the Government of India (GOI) has committed to redesigning their LPG policy, streamlining LPG access, and fostering increased LPG use by a combination of direct cash transfer programs (PAHAL), campaigns encouraging high income households to give up LPG subsidies (GiveItUp), and smaller LPG cylinders (Tripathi et al., 2015). There are few state level schemes, which also provide support to underserved population. The state government of Andhra Pradesh launched an LPG distribution scheme, *Deepam*, for rural BPL households in July 1999 (IndianExpress, 2011). Renewed efforts in the past 3-4 years to push LPG in rural households have witnessed rapid deployment of LPG under this scheme.

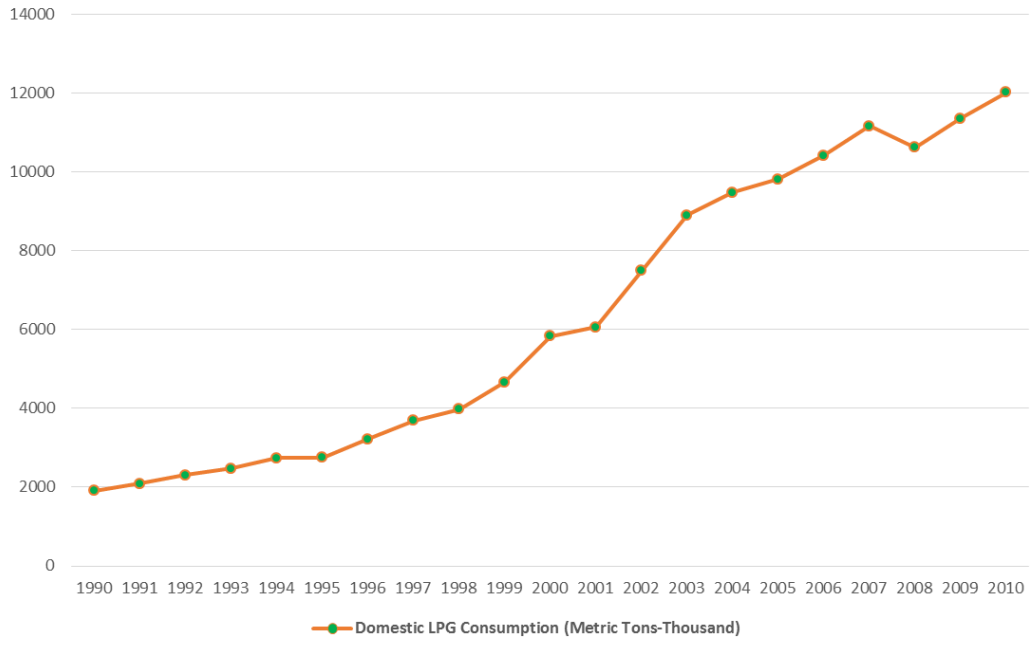


Figure 3: Indian LPG consumption trend (UN, 2015a)

Schemes like *Deepam* have waived upfront costs of acquiring LPG cylinders, opened rural distribution centers, and engages in awareness campaigns to foster increased LPG adoption and use. However, the absolute number of households in India using LPG is still very low. The 2011 Census indicates that only around 28.5% of Indian households reported LPG as their primary cooking fuel (Jain et al., 2014; Tripathi et al., 2015). Delineating these Indian households between rural and urban shows the skewed nature of LPG adoption and use. Figure 4 shows the percent distribution of households in rural and urban India, and Figure 5 shows use of LPG reported as primary cooking fuel in the rural and urban households. The percentage of households in rural areas is far higher than the percentage of households in urban areas (GoI, 2011). However, only around 11% rural households report LPG as their primary fuel compared to 35% urban households who report LPG as their primary fuel (Tripathi et al., 2015).

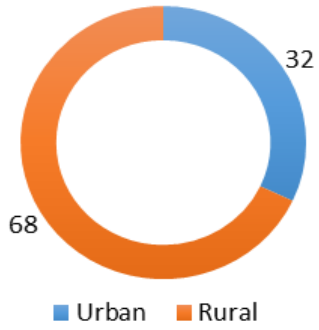


Figure 4:% Distribution of HHs in India (GoI, 2011)

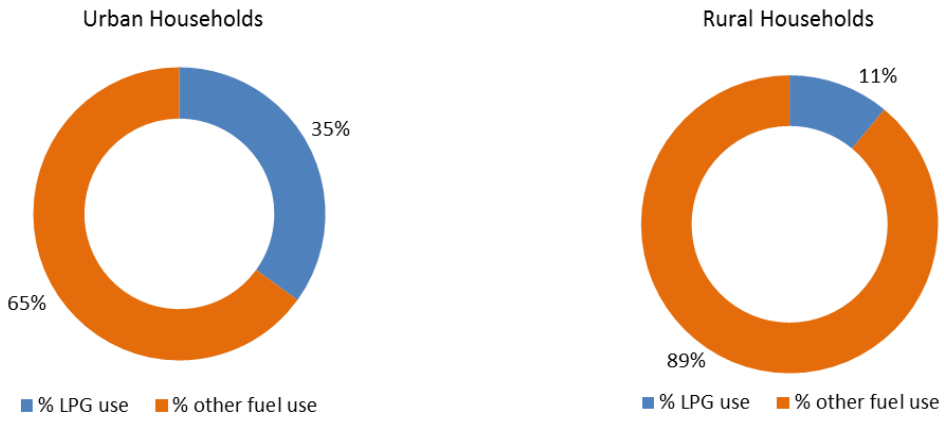


Figure 5: % Households with LPG use as primary fuel in: a) urban households and b) rural households (Tripathi et al., 2015)

2.4.1 Adoption and sustained use of LPG in rural India

The National Sample Survey Organization (NSSO) of India indicates that around 15% rural households bought LPG in India in 2011-2012. Evidence of an already low level of adoption of LPG in rural households is exacerbated by the fact that only 11% of them report LPG as their primary cooking fuel and could be termed as sustained and exclusive users (Tripathi et al., 2015). Although there may be a gradual increase in LPG adoption, the biomass consumption has not declined (see Figure 6) (Tripathi et al., 2015; UN, 2015a). This shows that increase in LPG adoption has not substituted the reliance on biomass (Jain et al., 2014; Tripathi et al., 2015). Stacking of LPG with traditional cooking technologies prevents health benefits to the rural poor (Ruiz-Mercado et al., 2013; Ruiz-Mercado et al., 2011; Yadama, 2013b). Systematic studies need to explore what it takes for the rural Indian households: 1) to increase the adoption rate of LPG, and 2) to increase sustained use of LPG by reducing stacking with traditional cooking systems. Low rate of adoption and of sustained use of LPG in rural areas is a combined outcome of low affordability, accessibility, and

awareness (3As) among rural poor households (Jain et al., 2014; Lewis & Pattanayak, 2012; Lucon et al., 2004; Kirk R. Smith & Sagar, 2014; Tripathi et al., 2015).

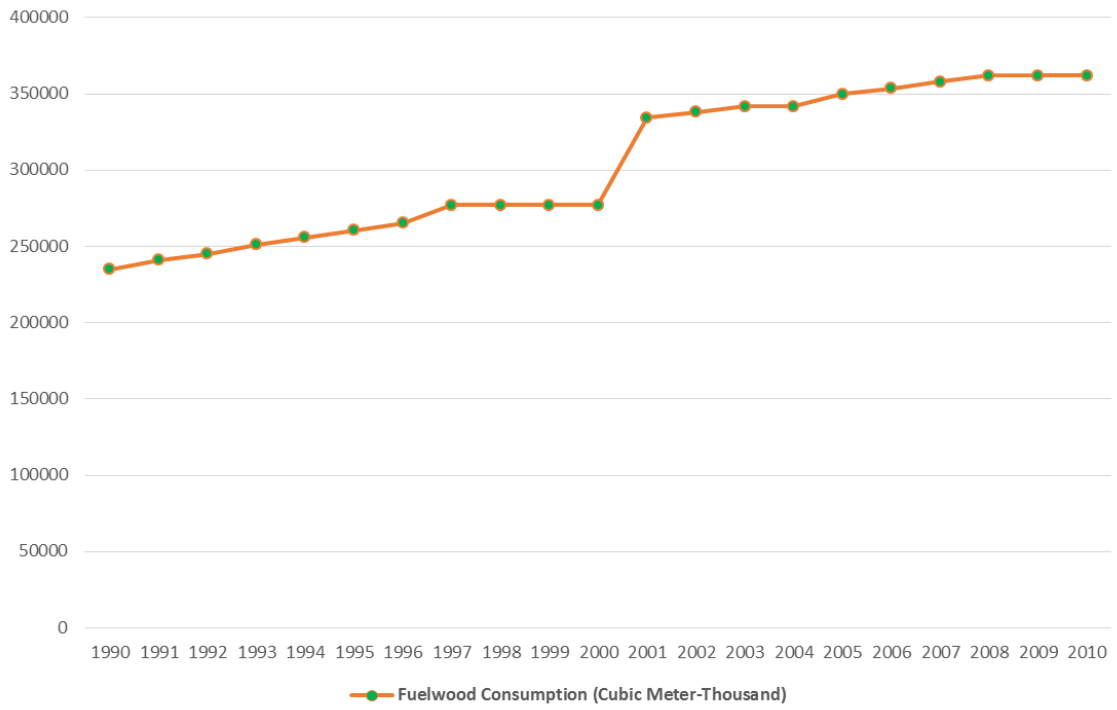


Figure 6: Fuelwood consumption trend in India (UN, 2015a)

2.4.2 Adoption and sustained use of LPG in rural India: role of affordability

Affordability of rural households to buy and use LPG can be analyzed through 2 separate perspectives: 1) provision of subsidies by the government, and 2) increase in income of rural households. At the current level of domestic LPG consumption, the Indian government provides subsidies of the order of approximately 8 billion USD (Jain et al., 2014). These subsidies intend to reduce the financial burden of LPG purchase and subsequent use by average domestic consumers. Closer analysis reveals that the 'blanket' or universal subsidy regime (irrespective of the income levels of consumers) has been unable to improve the situation of LPG adoption and use especially among the poor communities (Jain et al., 2014; Kirk R. Smith & Sagar, 2014). Even though the subsidy burden on the government has increased over the years, the benefit has been heavily skewed (Jain et al., 2014). The richest 30% households receive more than 50% of the LPG subsidies (Jain et

al., 2014). The poorest 30% households (which are predominantly rural) receive a meagre 15% of subsidies (Jain et al., 2014). Among the rural areas, the lowest income group decile spends around 8% of their monthly expenditure on LPG compared to a mere 3.3% by the highest income decile in rural areas (Jain et al., 2014). This is despite the mostly free availability of biomass in rural areas. The highest income group decile in the urban areas spends only 2% of their monthly expenditure on LPG (Jain et al., 2014). Clearly, a blanket subsidy has not benefitted the consumers (rural poor) for whom subsidies were particularly targeted and planned (Jain et al., 2014; Tripathi et al., 2015). In general, increase in rural household income impacts the adoption and use of LPG (Jain et al., 2014; Lucon et al., 2004; Kirk R. Smith & Sagar, 2014; Yadama, 2013a). This relationship is not insulated. There are additional social and economic factors such as caste, educational status of household head, women's decision making status in household, and availability of biomass, which might also impact LPG adoption and use, and they merit systematic investigation (El Tayeb Muneer & Mukhtar Mohamed, 2003; Jain et al., 2014; Lewis et al., 2015; Lewis & Pattanayak, 2012).

2.4.3 Adoption and sustained use of LPG in rural India: role of accessibility

In 2009, the central government launched the so called pro-poor LPG distribution scheme, *Rajiv Gandhi Grameen LPG Vitaran Yojana* (RGGLVY). The fundamental objective was to push LPG in the rural landscape of the country. Through this scheme, the central government entrusted the three prominent oil marketing companies (BPCL, IOCL, and HPCL) to set up low cost small rural distribution centers so as to cater to the rural poor communities (Tripathi et al., 2015). However, as on December 2014, the number of distribution centers catering to rural households under this scheme is extremely low compared to number of distribution centers in urban and semi-urban areas (see Figure 7). On similar lines with RGGLVY, various state governments such as Orissa, Karnataka, Bihar, and Andhra Pradesh (AP) also launched pro-poor LPG distribution schemes. The flagship *"Deepam"* scheme of AP targeted towards BPL rural households waives the upfront costs of

purchasing the LPG connection, and partners with women's self-help groups (SHG) for implementation and awareness creation. However, maintenance of these rural distribution centers has not been cost effective due to: 1) logistical challenges of procuring and storing LPG cylinders near rural areas, and 2) lukewarm demand from rural households despite the availability of LPG cylinders in these distribution centers (Jain et al., 2014; Tripathi et al., 2015). Poor rural infrastructure such as poor road networks connecting villages to distribution centers, absence of home delivery provisions by LPG distribution centers in these schemes, high transport costs, and high maintenance costs of LPG cylinders exacerbate low accessibility of LPG by rural poor households (Jain et al., 2014).

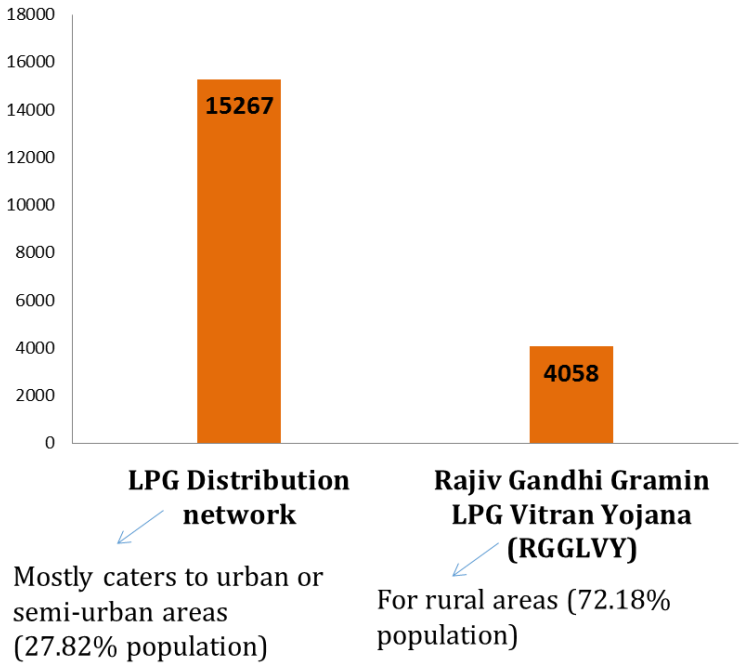


Figure 7: LPG distribution centers under RGGLVY for rural areas (Tripathi et al., 2015)

2.4.4 Adoption and sustained use of LPG in rural India: role of awareness

In urban areas, approximately 30% of energy needs for cooking from the top three income group deciles are derived from solid fuels (Jain et al., 2014). In rural areas, the energy needs from solid biomass fuels for cooking represents more than 50% even in the highest income group decile

(Jain et al., 2014). This shows that even if we control for adequate affordablity and accessibility of LPG, low awareness on HAP still impacts adoption and sustained use of LPG. Scattered rumour on safety issues with LPG cylinders deters communities to take up and sustainably use LPG in these households (Jain et al., 2014; Lewis & Pattanayak, 2012; Lucon et al., 2004). Ramirez, Dwivedi, Ghilardi, and Bailis (2013) reveal that adoption of cleaner cooking technologies relies on the passage of information and awareness through personal gender based networks among household or community members. While the exchange of information in close acquaintances are responsible for adoption and use of cleaner technologies, the flow of information between non-acquainted ties are also instrumental in pervading into entirely new communities (Ramirez et al., 2013).

2.5 Concluding remarks

Systematic research is needed to undertake a concurrent analysis of these 3As, and their impact on adoption and sustained use of LPG in rural hosueholds. Careful ascertainment of the elements of 3As could facilitate a model of a succesful pro-poor strategy for LPG adoption and sustained use.

III. Theoretical Framework

3.0 Organization of this chapter

This chapter is organized as follows. Section 3.1 introduces with the concept of implementation science in the context of adoption and sustained use of cleaner cooking interventions. This section explains the study from an implementation science perspective, describes the conceptual model, and the use of RE-AIM framework to evaluate the conceptual model. Studies placed within implementation science are frequently undertaken in two stages: 1) the first stage involves the development of a conceptual model derived with the help of classical theories in the field of environmental health or public health studies or theories that cut across multiple fields of study; 2) the second stage involves evaluation of the conceptual model using implementation science framework (Nilsen, 2015). Section 3.2, section 3.3, and section 3.4 discuss the three classical theories of energy poverty, structuration theory, and the theory of social capital. Section 3.5 crystallizes these three theories to develop a conceptual model highlighting the impact of affordability, accessibility, and awareness on the adoption and sustained use of LPG among energy poor communities. Section 3.6 discusses the concept of RE-AIM implementation science framework. This framework is a useful guide to conceptualize this study, construct research instruments, evaluate, and test the efficacy of the conceptual model of this study. Section 3.7 provides concluding remarks for this chapter.

3.1 Situating the current study within Implementation science

Studies of adoption and sustained use of public health interventions (such as LPG) form core components of implementation research to develop effective healthcare policy (Damschroder et al., 2009; Nilsen, 2015; Tabak, Khoong, Chambers, & Brownson, 2012). Implementation science refer to the scientific study of methods to integrate evidence-based health interventions in routine practice of usual settings (Brownson, Colditz, & Proctor, 2012; Damschroder et al., 2009; Durlak & DuPre,

2008; Eccles & Mittman, 2006; Fixsen, Naoom, Blase, Friedman, & Wallace, 2005; Tabak et al., 2012). The present study pertains to the domain of implementation science. Recent mounting interest involves exploring uptake and sustained use of public health interventions within a theoretical realm of implementation science. Research in implementation science can be approached in two stages: 1) Develop a conceptual model based on classical theories which are either unilateral or located at the interface of the substantive area and the implementation sciences domain; 2) test this conceptual model so developed with an evaluation framework offered by implementation science (R. E. Glasgow & Emmons, 2007; R. E. Glasgow, Vogt, & Boles, 1999; Nilsen, 2015). Curran, Bauer, Mittman, Pyne, and Stetler (2012) builds on Russell E. Glasgow, Lichtenstein, and Marcus (2003) and argue that such blending of design components could lead to rapid translational gains. Curran et al. (2012) modify this approach and term it as effectiveness-implementation hybrid research. Given this typology is currently underexplored and is still evolving (Curran et al., 2012), the current study follows the usual and more established term of implementation science to conceptualize the study design (Nilsen, 2015).

The two stages of development of the conceptual model and its evaluation is described as follows:

1. **Application of classical theories:** Nilsen (2015) emphasizes use of such classical theories, which cut across the substantive area (i.e. energy poverty) and implementation science. These classical theories may originate from fields external to implementation science (such as sociology, organizational behavior, economics, or business) and are used to explain aspects of implementation science research (adoption, sustained use, and maintenance of health interventions) (Nilsen, 2015). This chapter discussed energy ladder theory, Giddens' structuration theory, and theory of social capital to understand the determinants of adoption and sustained use of cleaner cooking systems such as LPG. An outcome of stage one was a

conceptual model on adoption and sustained use of LPG based on these three theoretical frameworks (see Figure 10).

2. **Use of evaluation frameworks:** Evaluation frameworks provide a guided structure to undertake implementation research (R. E. Glasgow & Emmons, 2007; R. E. Glasgow et al., 1999; Koorts & Gillison, 2015). This helps increase likelihood of developing better implementation strategies fostering increased adoption and sustained use of healthcare innovations (R. E. Glasgow & Emmons, 2007; R. E. Glasgow et al., 1999; Koorts & Gillison, 2015). This study applied the widely used implementation science RE-AIM evaluation framework to assess the conceptual model developed in stage 1 (see Figure 10) for this study. RE-AIM stands for Reach, Effectiveness, Adoption, Implementation, and Maintenance (R. E. Glasgow et al., 1999). RE-AIM framework has been successfully applied in implementation studies of public health interventions such as in nutrition, physical activity, and non-communicable diseases (R. E. Glasgow et al., 1999; Jauregui et al., 2015; Koorts & Gillison, 2015). Through the lens of RE-AIM evaluation framework, the study assessed the placement of conceptual model developed in stage 1 (see Figure 10) within implementation science.

The three classical theories used to explore determinants of adoption and sustained use of LPG in resource poor settings are discussed below.

3.2 Energy Ladder Model

Households using different forms of energy are distributed on an energy ladder constituting biomass fuels (dung, crop residues, wood), coal (or soft coke), fossil fuels (kerosene, LPG, and natural gas) and electricity (Leach, 1992; Masera et al., 2000; van der Kroon, Brouwer, & van Beukering, 2013). Increase in disposable income (which could be used on fuels) shifts these households from biomass use to cleaner fuel use on the energy ladder (Leach, 1992; Masera et al., 2000). Reducing the income poverty of a household reduces their energy poverty as they abandon

solid fuels and use cleaner fuels (Masera et al., 2000). This also means that as the income of the households increase, the preference for the energy sources increases on the ladder (Leach, 1992). This impacts the overall energy consumption of households (Masera et al., 2000; van der Kroon et al., 2013). The energy ladder model emphasizes the relationship between affordability, and adoption and use of cleaner cooking systems such as LPG (see Figure 8). Although this model has held significant sway in energy poverty research communities, yet it has 2 limitations: 1) affordability is a significant but only a partial driver motivating households to fuel switch (Lewis & Pattanayak, 2012); and 2) increase in income might motivate households to adopt cleaner cooking systems. However, there is strong evidence to show that solid fuels are never completely abandoned (Ruiz-Mercado et al., 2011). Simultaneous use of different forms of energy with increase in income shows that there are actually no discrete stages of energy uptake and use with increase in income.

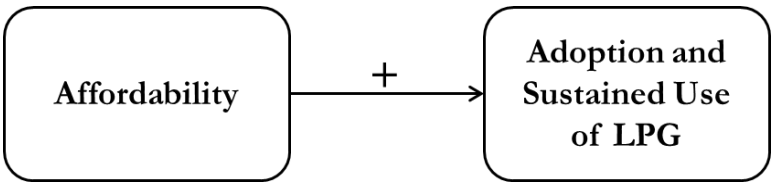


Figure 8: Impact of increase in income on LPG adoption and use (Energy Ladder Model)

van der Kroon et al. (2013) argues that in addition to affordability, impact of other household and institutional factors impact switching of fuel. These factors involve household and community norms, social structure, awareness level of households and communities, and other drivers such as accessibility to cleaner cooking systems (van der Kroon et al., 2013). Additional frameworks of structuration and social capital are needed to explore adoption and sustained use of cleaner cooking systems such as LPG.

3.3 Structuration theory

The central argument of Giddens' structuration theory is focused on relationship of the agent and the social structure. Giddens rejects earlier claims of autonomy of social structures and of

agents. The mutual exclusiveness of the subjectivism of human actions (or agents) and objectivism of social structures are flawed (Giddens, 1991, 1993). Giddens proposes that social structure and agents are a mutually constitutive duality. Social phenomena are a dynamic outcome resulting from the interaction of both social structure and agents (Giddens, 1990, 1991, 2013; Jones & Karsten, 2008). Without giving primacy to either social structure or agents, the theory argues that human agents draw on social structures in their actions and the social structures are produced and reproduced as a result of these human actions (Jones & Karsten, 2008). This recursive action creates and recreates social phenomena. Social structure is an outcome of the interaction between its agents and social structure itself. It recognizes that *"*man actively shapes the world he lives in at the same time as it shapes him*"* (Giddens, 1990).

3.3.1 Duality of structure

The key principle of structuration theory is the duality (the social structure and the agent) and non-static nature of social structure (Rose, 1999). Agents possess freedom within the structure, which enables them to produce, reproduce, and modify social structure over time (Giddens, 1991, 2013). The social structure is both a product of and constrain on human agents. In other words, there is an interdependence of structures and agency. The structures are continuously evolving. This process of structuration can be understood as follows: Every time social actions of human agents interact with modalities of social structure (stocks of knowledge, rules, and resources), social structure is produced and reproduced chronically over space and time (Giddens, 1990, 1991, 2013). There is a process of structuration through which social change occurs by the interaction between agents and structures. From every action of human agents new status orders emerge (Giddens, 1990; Jones & Karsten, 2008). This is an iterative process and is a defining aspect of social phenomena in time and space. Figure 9 below provides a visual representation of the recursive process of creation

and re-creation of social structure due to human actions (Giddens, 1990; Sarason, Dean, & Dillard, 2006).

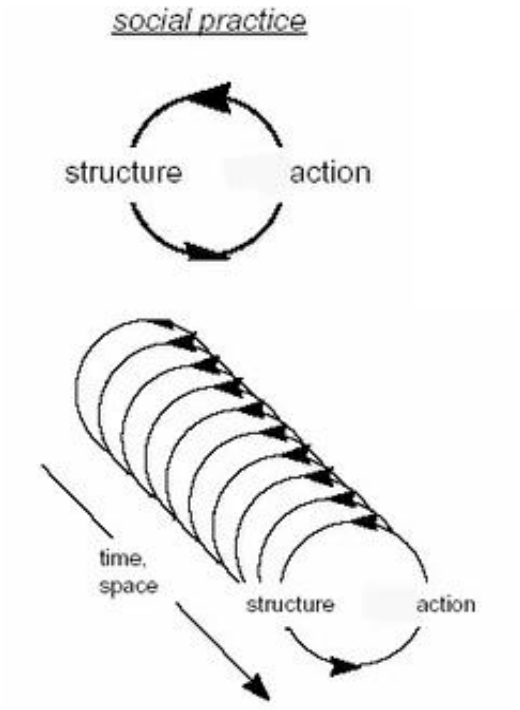


Figure 9: Duality and Dynamism of Social Structure (Rose, 1999)

3.3.2 Understanding adoption and use of LPG through structuration theory

Adoption and sustained use of cleaner cooking systems such as LPG by energy poor communities is a social product of human action constrained within specific structural modalities (norms, knowledge, and resources) (Yadama, 2013b; Yadama et al., 2012). Adoption and use are impacted by structural modalities of awareness, lack of perceptible incentives, misalignment of understanding between communities and implementers, accessibility to local distribution centers, and LPG cylinders' design issues (Lewis & Pattanayak, 2012; Yadama, 2013b). Social development and Public health implementers address these structural challenges. Their interventions of disseminating better technologies (such as LPG) among communities create a transition from existing status quo in communities into a new status quo (Nicholls & Cho, 2006; Sarason et al., 2006). Adoption of pro-poor financial strategy (to increase affordability), supply chain innovations

(to increase accessibility), and social marketing strategy (to increase awareness) are initiatives undertaken by implementers to move communities from existing status quo (use of traditional cooking technologies) to a new status quo (use of LPG). Community members move from using traditional technology to cleaner cooking technologies. Simultaneously, new social norms, structures, awareness and resources emerge in communities, which re-create a new social behaviors and systems. This recursive process of social evolution and mutual interaction between social structure and community members (human agents) continue in time and space.

The structuration theory provides an explanation for understanding how human agents embedded in social structures recreate the structure and recursively transform social modalities (Giddens, 1990, 1991, 1993, 2013). However, a fundamental limitation of the structuration theory is that it does not explain how adoption and sustained use of cleaner cooking technologies occurs over time. Abou-Zeid (2007) argue that the perspective of social capital bridges this chasm. Social networks among households are capitalized to bring in the desired change. Thus, the theory of social capital provides an additional lens to explore the adoption and sustained use of cleaner cooking systems such as LPG by these communities.

3.4 Theory of social capital

While the idea of social capital traces its roots in sociological literature for a long time, it was Loury (1977) and Bourdieu (1985) who are attributed to first use the term social capital in their corresponding research. Loury (1977) used social capital to discuss social position of individuals. An individual's social origin determines the amount of resources that needs to be invested in facilitating acquisition of human capital characteristics. Loury (1977) studied social capital in conjunction with the social origin of individuals. The consequences of social position lead to the development of social capital. However, no further systematic elaboration on social capital finds its place in his literature (Anheier, Gerhards, & Romo, 1995). Bourdieu (1985) is credited to further advance the

concept of social capital. Social capital is defined as "*the aggregate of the actual and potential resources which are linked to possession of a durable network of more or less institutionalized relationships of mutual acquaintance or recognition*" (Anheier et al., 1995; Bourdieu, 1985). Bourdieu (1985) argues that social networks are not social capital itself and the latter is an outcome of the former. He agrees with Loury (1977) that accumulation of social capital requires deliberate economic and cultural investment, which depend on social networks. Social capital reproduces a social class where the elites have better access to information due to their wider social networks. According to Bourdieu, the reserve of social capital possessed by an agent is determined by the totality of networks, which one can effectively mobilize through these networks (Anheier et al., 1995). Coleman (1988) extended the literature of social capital taking a functional recourse. He viewed social capital on the basis of its function. According to Coleman (1988) social capital is *"a variety of entities with two common elements: they all consist of some aspect of social structures and they facilitate certain action of actors-whether persons or corporate sectors-within the structure".* Social capital provides benefits, but can also require commitments. Coleman regards social capital as a function of accumulation of norms of reciprocity. Social capital is built by a set of norms and sanctions that allow individuals to cooperate for mutual advantage (Coleman, 1988). Coleman opines such mutual cooperation is possible when there are embedded obligations created by exchanges of benefits among connected entities (norms of reciprocity). More social capital is used, the more it grows (Adler & Kwon, 2002; Portes, 2000).

Although Loury, Bourdieu and Coleman have made significant contribution towards the concept of social capital, it is Putnam who is credited to draw a wider attention on this literature and presents the most contemporary definition of this concept. Putnam defined social capital as *"those features of social organization such as trust, norms, and networks that can improve the efficiency of society by facilitating coordinated actions"* (Woolcock & Narayan, 2000). Putnam's definition of social capital presents three components: moral obligations and norms, trust, and social networks. The central

thesis of Putnam's argument is based on the importance of social capital to shape economic system and political integration of a society. If a region has strong and well-functioning economic system complemented with successful political discourse, it is because of the region's successful accumulation of social capital (Putnam, 1995).

Analyzing a range of concepts and definitions on social capital, Adler and Kwon (2002) identify two content dimensions of social capital: structural and relational. The structural approach focuses on connections and ties among social agents. It comprises of the pattern of connections, density of networks, hierarchy and intensity of connections. The dominant metaphor in the structural approach of social capital is "it is who you know (rather than what you know)", which decides the flow of information. The structural approach views social capital as a glue that holds people together. The relational approach takes a critical tone on the structural approach of network connections of the social system (Ridley-Duff & Bull, 2011, p. 87). This approach argues that it is not the number of connections which matter but the quality and composition of relationships. The relational approach emphasizes on the importance of norms, trust, reciprocity and values as the key attributes of social capital and which needs to be considered to assess the accumulation of social capital. The summary of these two approaches are presented in Table 1 below.

Table 1: Structural and relational approaches to social capital (Adler & Kwon, 2002)

Structural	Relational
Networks	Trust
Connections	Norms
Weak and Strong Ties	Values
Bridges and Bonds	Attitudes
Actions	Reciprocity
Responsibilities	
Accountable Decision Making Processes	

While no single definition unites the disparate concepts on social capital, Nahapiet and Ghoshal (1998) and Adler and Kwon (2002) have synthesized social capital literature and their definitional concepts. A common thread emerging from them is the recognition that social capital comprises of social structures of relationships (ties), quality of these ties, and resources obtained through these social relationships. Adler and Kwon (2002) synthesize different social capital concepts in the literature by proposing that *"social capital is the goodwill available to individuals and groups. Its source lies in the structure and content of the actor's social relations. Its effects flow from influence, information and solidarity which are made available to the actor"*. Onyx and Bullen (2000) extend this argument and opine that existence of networks in social structure is a necessary, but not a sufficient condition, for accumulation of social capital. These networks need to be capitalized and mobilized into action by community based initiatives for generation of social capital. Onyx and Bullen (2000) term it as social agency while Woolcock and Narayan (2000) attribute it as organizational ability of the actors in the network.

3.4.1 Understanding adoption and use of LPG through theory of social capital

Low uptake of LPG and stacking with traditional cooking are critical challenges perpetuating energy poverty (Masera et al., 2000; Pine et al., 2011; Ruiz-Mercado et al., 2011; Shrimali et al., 2011). Slaski and Thurber (2009a) identify three reasons for these factors: 1) motivation, 2) affordability, and 3) level of user engagement. Motivation is connected with the degree of awareness of cleaner cooking technologies and their perceived value. Affordability is a function of disposable income to purchase cleaner cooking technologies, communities' willingness to pay, and cost of clean energy technologies. Slaski and Thurber (2009a) and Shrimali et al. (2011) emphasize that enhanced motivation can increase willingness to pay. User engagement is related with the scale of lifestyle change ushered in due to the use of cleaner cooking technologies. Relatively high gap in lifestyle changes may deter energy poor communities from adopting a cleaner technology, unless adequately

motivated. Motivation to use cleaner cooking technologies is a function of information and degree of awareness in the communities (Slaski & Thurber, 2009a). Perceived value of cleaner cooking technology can be enhanced by social marketing and advertising campaigns, which in turn again depends on quality of ties, social networks, and trust among energy poor communities (Ramirez et al., 2013; Slaski & Thurber, 2009a). Gender based networks of both men and women play a critical role in influencing peers in the communities to adopt newer and cleaner cooking technologies (Ramirez et al., 2013).

Degree of closeness among community members impact households' behavior in terms of health related decisions (such as fuel switch and use of cleaner fuels) (O'Malley, Arbesman, Steiger, Fowler, & Christakis, 2012). Also, as the number and quality of ties of a household with other households having a particular health choice increase, it impacts the household to engage in a similar health choice (O'Malley et al., 2012). Ramirez et al. (2013) extend these arguments and reveal the importance of opinion leaders in impacting cleaner cooking systems in communities. In addition to leaders from the formal institutional arrangements, Ramirez et al. (2013) emphasize the importance of teacher, religious leaders, local community leaders, and housewives in reinforcing the local information networks and disseminating relevant positive information.

Gender based personal networks also provide an important insight into LPG adoption. Same gender communication networks are more prevalent than cross-gender communication networks. The analysis of social capital underscores three critical insights into LPG adoption and sustained use: 1) the social structure of a system impacts dissemination of technological innovation (O'Malley et al., 2012). Networks, particularly informal personal networks, are potential mechanisms that can facilitate dissemination and implementation. They can contribute to understand both failures and successes in community's behavioral change endeavors to promote integration of evidence based practices; 2) In a gender segregated social system, analyses of gender based networks are critical for

understanding dissemination of innovation (Ramirez et al., 2013); 3) opinion leaders are influential in shaping, mediating or moderating the decision of the laggards regarding adoption, rejection, or abandonment of a technological innovation (Everett M Rogers, 2004; E. M. Rogers et al., 2005; Woodhouse et al., 1994).

3.5 Synthesis of classical theories to understand adoption and sustained use of LPG

The energy ladder model, structuration, and social capital theories are drawn from diverse academic disciplines. Still, they complement each other and help in developing a substantive understanding of the determinants of adoption and sustained use of cleaner cooking technologies like LPG in resource poor settings. We can synthesize the classical theories to reach the following key points: 1) increase in affordability is a significant yet an inadequate predictor of adoption and sustained use of LPG. Other household and institutional characteristics such as accessibility and awareness levels also impact LPG uptake and use; 2) determinants of adoption and use of LPG are an outcome of human action constrained by structural modalities pertaining to clean cooking such as lack of awareness and lack of accessibility to cleaner cooking systems. Targeted public health interventions help move communities from antiquated to newer social modalities. Newer social structure involves higher awareness levels and reduction in accessibility challenges. This recursive and dynamic process helps in abandonment of traditional cooking, and leads to adoption and use of cleaner cooking technologies such as LPG; 3) social network and ties among community members and public health interventionists lead to higher exchange of information and awareness on cooking. Health interventions can rely on social capital theory to increase awareness levels.

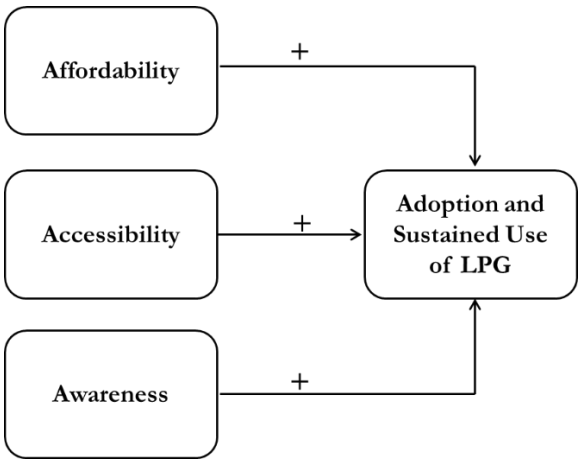


Figure 10: Impact of 3As on adoption and sustained use of LPG

Syntheses of these classical theories yield the above conceptual model **(see Figure 10)**[3]. In section 3.6, RE-AIM evaluation framework is discussed within the context of this study. The RE-AIM evaluation framework has been successfully applied to understand implementation of public health interventions.

As discussed earlier, RE-AIM evaluation framework is used to explore the placement of this conceptual model in implementation science research, development of research instruments, and subsequently to explore strategies adopted to test this conceptual model.

3.6 RE-AIM Evaluation Framework

The goal of implementation science is to develop the evidence base on effective health interventions that will produce the maximum impact in advancing research to practice and policy (Tabak et al., 2012). Approaching a study within an implementation science framework helps to develop evidence based strategies on how to promote the use of effective public health interventions in practice. RE-AIM is an evaluation framework frequently used in implementation science research. RE-AIM is a systematic framework, which examines a public health intervention, evaluates its

[3] Conceptual model (Figure 10) highlights that both adoption and sustained use of cleaner cooking systems are crucial for addressing household air pollution. This dissertation study, as part of the ISN grant, is confined to focus only on determinants of adoption of LPG. Exploring determinants of sustained use of LPG will succeed this dissertation study, but is beyond the scope of this current study.

potential for translating research into practice and policy, and bridges the research-practice gap (R. E. Glasgow et al., 1999; Jauregui et al., 2015). The different aims of this study find larger meaning and value when framed within the RE-AIM framework.

RE-AIM stands for **R**each, **E**ffectiveness, **A**doption, **I**mplementation, and **M**aintenance. The five dimensions of the RE-AIM framework provide a way to synthesize the findings from the two aims of this study: 1) **R**each is a measure of participation (R. E. Glasgow et al., 1999). It refers to the proportion of the target population that has participated in the intervention (R. E. Glasgow et al., 1999). Reach is concerned with the characteristics of the participants and whether they truly represent the target population (R. E. Glasgow et al., 1999; Jauregui et al., 2015). In understanding the rural poor LPG users now being reached, this dimension explores insights on how the program may improve its reach to larger proportion of rural poor households. Aim 1 of the study collected demographic characteristics to answer this dimension of the RE-AIM framework; 2) **E**ffectiveness refers to the success rate of the health intervention, if implemented (R. E. Glasgow et al., 1999; Jauregui et al., 2015). The evidence based technology in this study was LPG. The effectiveness of LPG has been established by the WHO. LPG meets all the required IAQG (Kirk R. Smith & Sagar, 2014). Effectiveness also concerns improvement in quality of life and reputational outcomes for households using LPG; 3) **A**doption refers to the absolute number or proportion of the target population who take up an evidence based health intervention (R. E. Glasgow et al., 1999). Adoption is usually assessed by direct observation or structured interviews (R. E. Glasgow et al., 1999). The study examined adoption of LPG in aim 1 through the household adoption questionnaire. Predictors pertaining to three concepts of affordability, accessibility, and awareness (3As) were explored in aim 1. Relative influence of gender based networks on LPG adoption was assessed in aim 2 as a key component of the awareness dimension of the conceptual model (Jain & Agrawal; Jain et al., 2014; Tripathi et al., 2015); 4) **I**mplementation refers to the fidelity to LPG use,

and adherence to the distribution program of LPG delivery as it is intended, so as to foster adoption and sustained use of LPG (R. E. Glasgow et al., 1999; Jauregui et al., 2015; Koorts & Gillison, 2015). Through the LPG adoption questionnaire in aim 1, the study examined the 3As to assess if the LPG distributors and the government reliably provided support for adoption and sustained use of LPG. In this study, the dimension of implementation was examined from the perspective of the users. Two factors related to implementation were assessed to explore adoption of LPG by users: 1) awareness campaigns hosted by *gram panchayats* (local village level self-governments), oil marketing companies, or government; and 2) membership of respondents in SHGs. The supply side perspective of implementation was not examined in this study; 5) **M**aintenance measures the extent to which the intervention has been integrated in the routine practices of the participants (R. E. Glasgow et al., 1999). It is accompanied by a change in practice patterns of the participants to sustainably endure the health intervention without any intention of abandonment (R. E. Glasgow et al., 1999). The three dimensions of RE-AIM namely adoption, implementation, and maintenance merit systematic study and are crucial for addressing household air pollution. This dissertation study, as part of the ISN grant, was confined to focus specifically on determinants of adoption of LPG. Exploring determinants of "maintenance" of LPG as the 5th dimension of the RE-AIM evaluation framework will immediately succeed this study as part of the larger ISN grant, but is beyond the scope of this dissertation study.

3.7 Concluding remarks

Classical theories of social capital, structuration, and energy ladder model suggest that both household and organizational level factors- specifically the 3As- determine adoption and sustained use of LPG. Each of the factors in the 3As is crucial for analysis. Relative significance of these factors is contextual and may depend on economic, social, and cultural characteristics of the communities under study. Concurrent analyses of these three factors facilitate the development of a

successful dissemination and implementation strategy for LPG in resource poor settings. The construction of this implementation research, assessment of the conceptual model, development of questionnaires, operationalization of measures, and proposed analysis on LPG adoption are guided by the RE-AIM evaluation framework. Chapter 4 discusses the method of the study.

IV. Methods

4.0 Organization of this chapter

Section 4.1 of this chapter provides an overview of the methodological innovation introduced in this study. Section 4.2 discusses the overall approach of the study. This section discusses how the RE-AIM evaluation framework informs the placement, construction of instruments, and trajectory adopted for the data analyses of this study. Section 4.3 discusses the strategy for sampling and for recruitment of respondents in this study. Section 4.4 discusses the data collection strategy for aim 1 (adoption), while section 4.5 discusses the data collection strategy for aim 2 (personal network analysis). Section 4.6 covers different types of research instruments deployed to undertake aim 1 and aim 2 of the study. Section 4.7 discusses the data analyses strategy for aim 1, while section 4.8 discusses the data analyses strategy for aim 2. Section 4.9 concludes.

4.1 Overview

This study brought two novel approaches to gain new insights into:

1. Apply the RE-AIM (Reach, Effectiveness, Adoption, Implementation, and Maintenance) framework to explore LPG adoption. The RE-AIM framework guided this research including development of questionnaires for reach, adoption, and implementation dimension of this study.
2. Deploy egocentric network analysis to understand how gender based ego networks matter in adoption of LPG.

In combining these approaches, this study was able to: 1) examine the pooled impact of the 3As on LPG adoption absent in the present stock of research; 2) assess the association of personal gender based networks of men and women with LPG adoption, contributing to our understanding of the role of gender based networks in the implementation of clean cooking, 3) understand these effects through the RE-AIM framework to apply our insights toward implementation of cleaner

fuels and advance implementation science in the clean cooking sector. This is the first systematic study: 1) to apply the RE-AIM framework in exploring determinants of adoption of cleaner cooking systems (LPG) for rural poor; and 2) to use gender based personal networks to analyze LPG adoption in rural India. Also, this study is a first systematic attempt to undertake a quantitative examination of the concurrent impact of affordability, accessibility, and awareness related factors on the adoption of LPG.

Lessons drawn from this study are timely, relevant, and of interest to Government of India's renewed policy planning (including provisions in annual budget 2016) and implementation to expand LPG distribution to the poor in rural India. The Government of India has committed to redesign their LPG policy and distribution to penetrate rural communities using a combination of direct cash transfer programs (PAHAL), and campaigns encouraging non-poor to give up LPG subsidies (GiveItUp) (Tripathi et al., 2015).

4.2 Approach

The overall goal of this study was to derive new insights on the reach of LPG among the poor in rural India, and factors that influence adoption (initial uptake) of LPG in BPL households of rural India. There were two specific lines of inquiry of this study:

Aim 1: To understand how rural LPG adopters vary from other rural households on factors of affordability, accessibility, and awareness of LPG *(aim 1: adoption)*

Aim 2: To evaluate the relative influence of gender based personal networks on LPG adoption in rural households *(aim 2: personal network analysis)*

This was a quantitative case control study (Song & Chung, 2010). Adoption of technology by communities (such as LPG adoption by the poor) has a long latency period, and is impacted by multiple parameters from social, economic, and technological domains (Slaski & Thurber, 2009b). Case-control studies are suited for such topics, which have long latency period (Song & Chung,

2010). These studies are relatively inexpensive to implement, and allow for simultaneous analysis of multiple determinants (Song & Chung, 2010).

This study tested the substantive conceptual model shown in Figure 10. Different stove adoption related studies have defined adoption and sustained use in ways specific to their studies. It was imperative to define those 5 concepts, which informed this particular study: 1) Adoption refers to the initial uptake of LPG (GACC, 2015, 2016). Adoption of LPG is independent of the behavioral phenomena of sustained use of LPG or stacking LPG with traditional stoves. Adoption of LPG was a dichotomous outcome variable (LPG adoption: yes/no) in this study; 2) sustained use[4] shows the degree to which LPG is used in the participant's households (GACC, 2015, 2016). Sustained users who exclusively use LPG make a complete transition to LPG with no intention of reverting to traditional stoves or traditional fuels (GACC, 2016); 3) in relation with implementation science studies, affordability refers to the maximum possible capacity of households to pay for the minimum level of services (Jain et al., 2014). Affordability is impacted (but not limited to) by household factors such as income, and also by national economic policies on subsidies (Jain et al., 2014); 4) accessibility of LPG indicates factors impacting households to procure LPG cylinders and stoves when needed. Factors affecting accessibility include (but not limited to) distance of rural LPG distribution center, delivery mechanism of LPG cylinders, and road connectivity from villages to local distribution centers (Jain et al., 2014); 5) awareness refers to the degree of knowledge, information, and perception about LPG stoves, their adoption and use (Lewis & Pattanayak, 2012). Several studies recognize the significance of awareness in motivating households for a fuel switch (Lewis et al., 2015; Lewis & Pattanayak, 2012). Scattered evidence suggests that low information and scattered rumors (especially through personal networks) on LPG safety issues may act as a deterrent to uptake and use of LPG by these rural households (Jain et al., 2014).

[4] Analysis on "sustained use" is beyond the scope of the current study, but will be conducted as part of this ISN grant, which will succeed this dissertation study.

Variables pertaining to affordability, accessibility, and awareness were predictors for outcome variable LPG adoption (aim 1) in this study. One of the key sources of awareness is the information received from our personal networks (Dhand, Luke, Lang, & Lee, 2016; Ramirez et al., 2013). Personal networks determine information reaching to egos (Dhand et al., 2016; Ramirez et al., 2013). Examination of personal networks could reveal strong insights on LPG adoption behavior of poor communities. Aim 2 undertakes personal network analyses by evaluating the structure and composition of gender based ego networks. Knowledge and awareness flows through networks and consequently impacts decision of LPG adoption among households (Ramirez et al., 2013). In the context of personal networks or ego networks, egos are the focal nodes or the individuals, whose structure and composition of personal networks are under investigation. In this study, the personal networks of LPG adopters (women respondents and men respondents) and non-LPG adopters (women respondents and men respondents) were examined. These women and men respondents were the egos. The node to which ego is directly connected to are called alters. Each alter is connected with an ego. Multiple alters can have one ego. This ego-alter connections form a personal network of an ego.

As discussed in chapter 3, the construction of this study was guided by the RE-AIM evaluation framework. A summary showing the placement of the conceptual model (Figure 10) within the RE-AIM framework of implementation science is provided in Figure 11. Development of research instruments was undertaken in line with the RE-AIM framework to explore understanding of critical elements, which could impact adoption of LPG by the poor. Evidence-based interventions using this framework could inform improved understanding of adoption of LPG in resource poor settings.

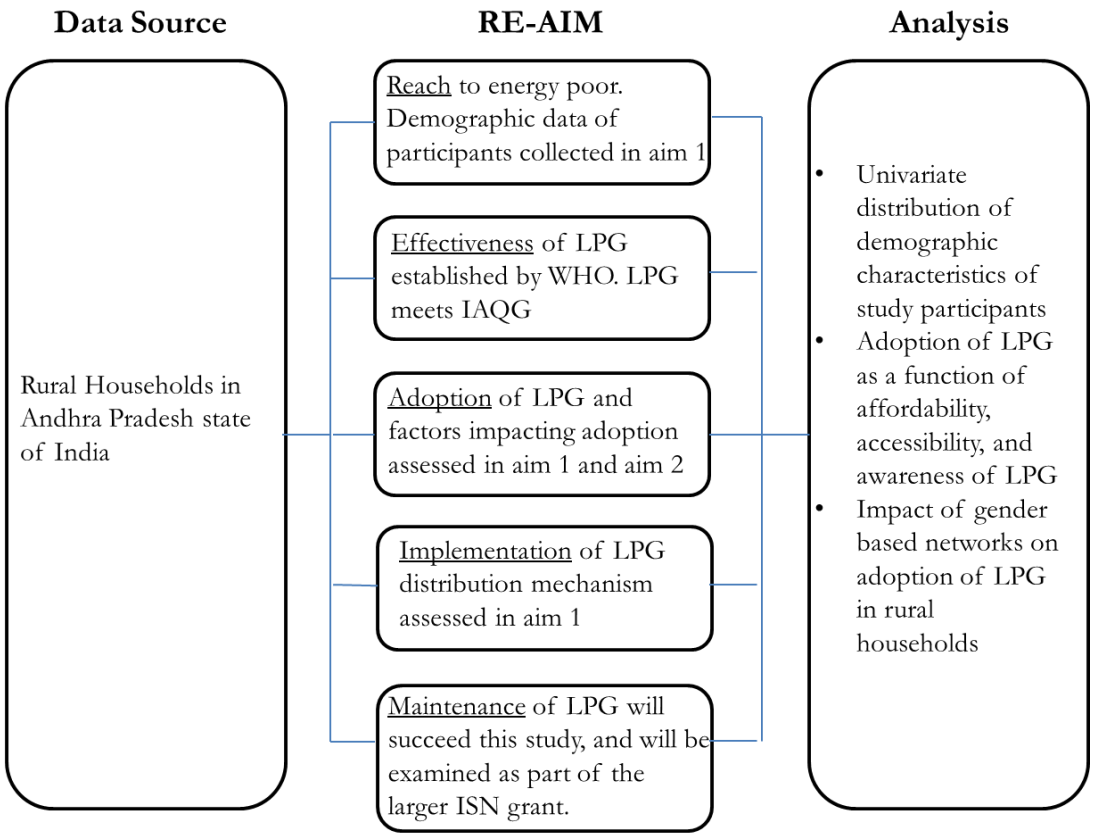


Figure 11: RE-AIM framework to analyze determinants of adoption of LPG (R. E. Glasgow et al., 1999)

4.3 Sampling and recruitment

A case control approach (Song & Chung, 2010) was undertaken to conduct this study. Equal number of case and control households was selected for this study (control to case ratio was 1). A sample size of 255 households was selected each for case (LPG adopter households) and control (LPG non-adopter households). A total sample size of 510 households at a 95% confidence level (alpha=.05) provided a power of 80% to this study at a control to case ratio of 1:1. This computation assumed that the populations mean difference in monthly income was 545.35 India National Rupee (INR), and the common within-group standard deviation was 2199.26 INR per month. In the absence of previously published studies on rural income in this region, the power computation was conducted using a baseline income data from another recently concluded NIEHS

funded R21 (WUSTL IRB ID# 201207016) randomized controlled trial (RCT) on cookstoves. This dissertation study was conducted in the same region where the RCT was undertaken. A secondary benefit of this case control study was to contribute in estimating insights on effect size, which could be utilized for a larger R01 study on adoption and sustained use of LPG in such resource poor settings in rural India. Notes on sample size calculation are provided in appendix 2.

To facilitate sampling, the implementing partner for this study, Foundation of Ecological Security (FES), collected the required background data on key demographic characteristics of the habitations[5] in these *mandals* (blocks), and of the households in these habitations. A multistage random sampling was used to select households in rural habitations of Thambalpalle and Peddamandyam *mandals* (block) in Chittoor district of Andhra Pradesh state in India. To facilitate sample selection, an exhaustive list of habitations (and households in these habitations) was generated with 4 key variables: 1) distance to nearest LPG distribution center; 2) dominant caste of the habitation; 3) number of households in each habitation; 4) presence of LPG adopters in these habitations. Multistage sample selection process was conducted through the following steps in their respective order:

1. **Sample of villages:** Stratified random sampling was used to select the list of villages for the study. The selection criteria were:

a. Proximity to the nearest LPG distribution center: Based on the distance from the nearest LPG refilling and distribution center, the exhaustive list of habitations (i.e. habitations population list) was divided in 2 sub-groups by taking a median split of the distance from the nearest LPG refilling and distribution center: 1) nearer to the center, and 2) far from the center.

[5] A habitation is a distinct cluster of houses. In rural India, a village may include one or more habitations. One of these habitations (usually the most populous) have the same name as the village name.

b. Dominant caste of the habitation: The habitations population list was divided in 3 sub-groups: General Caste, Other Backward Castes (OBC), and Scheduled Castes/Scheduled Tribes (SC/ST).

Theoretically, these two stratifying variables and their subgroups led to 6 distinct strata (2subgroups*3subgroups). The habitations population list was finally divided across these 6 distinct strata. Using a disproportionate stratified random sampling technique, a total sample of 35 habitations was selected from these 6 distinct strata. Disproportionate stratification of habitations served two purposes: 1) it was important to keep adequate no. of habitations in the list to select households from, in case of selected habitations do not consent for the study or drop out during the study; 2) one additional habitation in stratum 5 was a large, OBC dominated, relatively socially and economically backward, and a remote habitation. Selection of an adequate number of households for both case and control groups from this habitation was crucial. Appendix 3 shows a list of the 6 distinct strata that was used to select the 35 habitations. The random order generator of SAS version 9.2 was used to select the sample habitations from the habitations population list.

2. In the next stage of the multistage sampling of this study, quota sampling was used to select case and control group households from selected habitations. From each of the selected sample habitations, all the LPG adopter households (case) were selected, and as many non-LPG adopters (control) were also selected. If the number of non-LPG adopters was smaller than the number of LPG adopters in a selected habitation, all the non-LPG adopters (control) were selected, and as many LPG adopters (case) were selected. This ensured that the control to case ratio of 1:1 was respected within each habitation.

4.3.1 Study participants (N=510; 255 from each group)

The inclusion criteria for the study participants were: rural household with an adult male and adult female member (>18 years age), woman respondent who was able to provide consent for the

study, the woman respondent was the primary cook of the house, senior most male respondent (or primary decision maker in the household) who was able to provide consent for the study, women respondent resided in the household for the last 12 months, women respondent planned to reside in the household for at least 12 months from the date of enrollment for the study. An additional inclusion criterion for case group (LPG adopter households) was: household received the first LPG cylinder in the last 12 months from the date of enrollment for the study. The LPG study eligibility questionnaire is provided as appendix 6.

4.4 Data collection for aim 1 (adoption)

Aim 1: To understand how rural LPG adopters vary from other rural households on factors of affordability, accessibility, and awareness of LPG

A structured household adoption questionnaire was used to record data on social, economic, and demographic characteristics. Women (primary cook) from each household were the respondent to this questionnaire. In addition to household demographic characteristics, the questionnaire recorded data pertaining to the 3 significant drivers impacting LPG adoption: affordability, accessibility, and awareness (3As) of LPG. The categorical outcome variable for aim 1 was adoption of LPG at the time when data collection was undertaken for the household. Candidate predictor variables on "affordability" included last month average household income, last month income of the respondent, land ownership, and membership with self-help groups. Candidate predictor variables on "accessibility" included distance of households from nearest LPG distribution centers, presence of paved roads to LPG distribution centers, and preferential size of LPG cylinders, and biomass availability. Candidate predictor variables on "awareness" included government promotion campaign, and perceptions about LPG in enhancing social status. Key control variables that were recorded are caste, age, and education of the respondent. The adoption questionnaire for aim 1 was administered to all 510 households. The indicators to assess affordability, accessibility, and

awareness were adapted mainly from three standard instruments: 1) DHS questionnaires; 2) National Sample Survey Organization (NSSO) of India; and 3) Census of India 2011 questionnaires. In addition, multiple qualitative manuscripts and reports were also examined. The questionnaire is provided as appendix 7. The data were entered in the RedCap database management system, a secure web application for building and managing online surveys and databases.

4.5 Data collection for aim 2 (personal network analysis)

Aim 2: To evaluate the relative influence of gender based personal networks on LPG adoption in rural households

Personal social networks of homogenous communities influence awareness levels, which in turn drive adoption, implementation, and maintenance of stoves (Ramirez et al., 2013). Implementation of health interventions are strongly impacted by personal social networks (Mohammed, 2001; Ramirez et al., 2013). Both men and women play a critical role in adopting, implementing, and maintaining cleaner cooking technologies like LPG (Ramirez et al., 2013). Thus, it was critical to assess the ego networks of study participants to ascertain the structure and composition of their networks, which influence their awareness and decision making capacity. To generate a personal network data, an ego network survey was used to probe the women (primary cook) and the adult male (or primary decision maker) of the selected households in the sample, and their corresponding personal social networks were explored. This approach was novel in understanding the role of personal networks and their potential impact on the LPG adoption behavior of the respondents. Personal network analyses or egocentric network analyses focus on the structure and composition of the networks surrounding a target individual (O'malley, Arbesman, Steiger, Fowler, & Christakis, 2012) referred to as "ego." A well-established ego-centric network survey instrument was used to measure gender based personal networks. The network data were collected as follows (Burt, 1984; Dhand et al., 2016): 1) the survey began with three name generator

questions to prompt identification of individuals who give advice, socialize, and support the respondent; 2) After eliciting the network members, a second set of questions was performed to evaluate the strength of the connections (tie strength) between the respondent and the individuals identified by the respondent; 3) subsequently, the strength of the connections between the network members identified was probed; 4) finally, characteristics of the network members identified were solicited (e.g., their demographics, income, household size, cooking habits, and LPG adoption status). The personal network survey instruments for women and for men are provided as appendix 8 and appendix 9 respectively.

4.6 Research instruments

A summary of the research instruments is provided in table 2 below. Each of the research instruments was drafted in English, and then translated in Telugu (local language of the region).

Table 2: Data collection instruments

Conceptual domains	Aims	Research instrument	Data source
Adoption of LPG	Aim 1	Adoption questionnaire (appendix 7)	Households: women
Personal social networks of LPG adopters and non-LPG adopters	Aim 2	personal network survey questionnaires for women and men (appendix 8 and appendix 9)	Households: women, men

Cognitive Response Testing

For each question developed for this study, a series of approximately 10-15 individual interviews for cognitive response testing (CRT) were undertaken during the instrument testing phase. Testing was complete when saturation occurred (i.e., when the same themes repeatedly emerge). Cognitive response testing is routinely used in refining questionnaires to improve the quality of data collection (Willis, 2004). Testing determined: 1) question comprehension (e.g., what did specific words or phrases in the question mean to the respondent); 2) information retrieval (e.g., what information did the respondent need to recall in order for answering the question); and 3)

decision processing (e.g., How did they choose their answer?). CRT was conducted during testing until questions were modified to invoke the same "conceptual semantics" (Willis, 2004), which the enumerators wanted from the respondents through these questions.

4.7 Data analysis for aim 1 (adoption)

Aim 1: To understand how rural LPG adopters vary from other rural households on factors of affordability, accessibility, and awareness of LPG

Data analysis for aim 1 was undertaken in the following sequence of 1 through 4. R version 3.0.3 was used for all analyses.

1. **Univariate analyses:** To explore sample characteristics of the data and to assess the overall data distribution, univariate analyses were conducted. Descriptive statistics were generated for each of the variables. Mean, median, standard deviation (SD), and interquartile range (IQR) were generated for continuous variables, while frequency distribution and percent distribution were generated for categorical variables. It was ensured that there were no missing values by following up with the study households. In case of missing values encountered, enumerators went back to the respective households to explore the data for those missing values. Table 3 shows the summary description and corresponding codes of the variables that were used to explore aim 1 of this study.
2. **Bivariate analyses:** To determine the strength and direction of association at a bivariate level between each of the independent variables with the dependent variable (adoption of LPG), bivariate analyses were conducted. Since the dependent variable (adoption of LPG: yes/no) was a nominal variable, chi-square was conducted to examine associations with categorical predictors. To undertake bivariate association between the dependent variable and continuous predictors showing normality of observations, Welch's independent samples t-test (t) was conducted. Welch's t-test requires normality of observations. Non-parametric Mann Whitney

U test (w) was conducted to analyze bivariate association between outcome variable and those continuous predictors, which did not show normality of observations.

3. **Diagnostic tests for binomial logistic regression models:** Following assumption tests were conducted before undertaking binomial logistic regressions:

a. Responses were independent, mutually exclusive, and exhaustive.

b. The dependent variable was nominal while the independent variables were nominal or continuous (interval/ratio).

c. The minimum number of observations for each of the variables was at least 50.

d. There was an association between (at least one) independent variable and the dependent variable.

e. There was no multicollinearity among the independent variables.

f. The model fitted the data.

Assumptions a, b, and c were examined through univariate analyses (stage 1), while assumption d was examined through bivariate analyses (stage 2). To assess multicollinearity (assumption e), variance inflation factor (VIF) results were examined for predictors used in each of the 5 binomial regression models. The VIF should be less than 4 (normally accepted value) for the predictors to pass the multicollinearity assumption tests. To assess the stability and overall model fit (assumption f), Hosmer and Lemeshow goodness of fit test was conducted, and ROC curves were simultaneously plotted for all the 5 regression models. The Hosmer and Lemeshow goodness of fit test should be statistically non-significant, and the area under the ROC curve should be higher than 0.70 (normally accepted value) to deduce that regression models are stable and are fitting the data. Unlike linear regression or generalized linear models (OLS), binomial logistic regression models do not require the following assumptions: 1) linearity; 2) normality; and 3) homoscedasticity (Morrow-Howell & Proctor, 1993; Press & Wilson, 1978). Thus, while building regression models for research

aim 1, transformation of non-normal predictors was **not** undertaken. Transformations change the metric of the variable occasionally impacting odds ratios in logistic regression (Press & Wilson, 1978). Non-transformation maintains the predictive capacity of the logistic regression models (Press & Wilson, 1978).

4. **Binomial logistic regression models:** The research hypotheses for aim 1 of the study were explored by examining the effect of affordability, accessibility, and awareness related measures on adoption of LPG. Categorical outcome variable for aim 1 was the adoption of LPG (options: yes/no). A total of 5 binomial regression models predicting adoption of LPG (reference category: non-adoption of LPG) were analyzed, which controlled for the predictors shown in Table 3. A forward selection stepwise regression approach was used. This approach involves sequential addition of variables based on pre-defined set criteria (set of hypotheses for aim 1) till a final model is built, with all the variables as required by that pre-defined criteria. For this study, stepwise regression was useful in 2 ways: 1) to explore the impact of affordability, accessibility, and awareness (3As) individually in 3 separate models, while controlling for the demographic variables; 2) to examine the relative contribution of 3As when all the measures of 3As were included in the model, while controlling for the demographic variables. The study developed 5 regression models. Model 1 included only demographic predictors. Model 2, model 3, and model 4 respectively included the affordability, accessibility, and awareness related predictors, while controlling for the demographic predictors. Model 5 was built on model 1, model 2, model 3, and model 4 to include all the predictors of 3As to explore the hypotheses of research aim 1. Corresponding AIC and log likelihood values were calculated to assess the relative fitting and model comparison among these 5 regression models. McFadden's R square values were analyzed to explore the predictive capacity of the models. The alpha value or the significance level for this

study was fixed as 0.05. Predictors with p-values below 0.05 were considered statistically significant for this study.

Table 3: List of variables and corresponding codes for aim 1

Outcome Variable for aim 1	**Codes**
LPG Adoption	Yes/No
Demographic predictor variables	**Codes**
Age	Years
Marital Status	Married/Unmarried/Widow/Divorced
Literacy: Highest level of education completed	None/Below or up to class 4/Class 5 to class 8/ Class 9 to class 10/ Class 11 to class 12/College
Literacy: Highest education of male decision maker	None/Below or up to class 4/Class 5 to class 8/ Class 9 to class 10/ Class 11 to class 12/College/Not Applicable
Caste	General®/Other Backward Castes (OBC)/Scheduled Castes/Scheduled Tribes [SC/ST]/Other religious minorities/Others
Affordability related predictor variables	**Codes**
Last month income of the respondent	Indian National Rupee (INR)
Membership of Self-Help Groups (SHGs)	Yes/No
Last month income of the household	Indian National Rupee (INR)
Land ownership of the household	Acres
Agricultural debt owed by the household	Indian National Rupee (INR)
Accessibility related predictor variables	**Codes**
Nearest tarmac road from the household	Kilometers (Km)
Nearest LPG distribution center	Kilometers (Km)
Preference for smaller LPG cylinders	Yes/No/Can't say
Availability of free biomass near the household	Yes/No/Can't say
Distance of the biomass source	Kilometers (Km)
Decision making capacity to purchase new stove	Respondent/Spouse of respondent/Respondent and spouse of the respondent/Respondent, spouse of the respondent, and others/Respondent and other but not the spouse/Others but not the respondent or the spouse of the respondent
Awareness related predictor variables	**Codes**
Perception of LPG explosion on adoption	Yes/No/Can't say

LPG against household traditional culture	Yes/No/Can't say
LPG enhance social status	Yes/No/Can't say
Campaigns attended	Yes/No

4.8 Data analysis for aim 2 (personal network analysis)

Analyses of personal networks were undertaken in two separate stages: 1) structural analyses; and 2) composition analyses. Structural analysis examines the organization of ties between egos and alters. It involves examination of patterns of association between them (Dhand et al., 2016). Composition analysis examines the characteristics of alters relative to their egos (Dhand et al., 2016). Aim 2 of the study explored structural and composition analysis of 4 groups of data: 1) women from the case group households adopting LPG (LPG women); 2) men from the corresponding case group households adopting LPG (LPG men); 3) women from the control group households not adopting LPG (non-LPG women); 4) men from the corresponding control group households not adopting LPG (non-LPG men). Bivariate analyses were preceded by structural and composition analyses. Bivariate analyses were undertaken to ascertain statistically significant difference in structural and compositional characteristics of these 4 groups. This was done to test the hypotheses of aim 2. R version 3.0.3 was used for all analyses. Stages of data analyses of aim 2 are discussed below in detail.

1. Structural analysis

There are 3 types of structural analyses that were conducted in this study. Details of these 3 types of structural analyses are discussed below.

a. Network size: This is typically measured by the total number of nodes in the network after excluding the node of the ego (Dhand et al., 2016). For instance, if an ego reports having 7 connections, the network size is 7.

b. Network density: This is a measure of network cohesiveness, and is the ratio of existing number of ties to the maximum possible ties possible. It is measured as the number of real ties among

alters divided by the maximum possible number of ties among network members (Dhand et al., 2016). Network density is measured as:

$$\frac{\boldsymbol{2 * L}}{\boldsymbol{N * (N - 1)}}$$

Where L is the number of observed ties, and N is the number of nodes.

A personal network with a relatively higher network density will be more clustered and close-knitted. Such networks have a higher likelihood to be constrained. Granovetter (1985) explains that a highly dense network increases the likelihood to exert social pressure among network peers because it is more likely that "everyone knows everyone else." Dissemination of novel information slows down in relatively high density networks. This assertion however, is partially true. Social capital in a network is determined not only by the number of people in a network but also by the quality of the ties among them (Adler & Kwon, 2002). Thus, in addition to network density, structural holes are also significant to assess the likelihood of information dissemination in networks. Structural holes (discussed below) account for both number of nodes in a network and the quality of ties among them.

c. Structural holes: Certain structures of personal networks provide egos with newer information and opportunities. This is a function of how alters are positioned around egos and the corresponding alter-alter association. Absence of alter-alter connection around an ego creates a structural hole in the corresponding personal network. Structural holes provide an opportunity to egos to act as bridges between these alters. The likelihood for egos to receive novel information, newer insights, or opportunities increases with increase in structural holes in their personal networks (see figure 12). Structural holes are examined by a measure called effective size. Effective size denotes the number of non-redundant nodes of a personal network. Effective size is measured by:

$$\sum_{j}\left[1-\sum_{q}(\boldsymbol{p_{iq}}*\boldsymbol{m_{jq}})\right]$$

Where $q \neq i,j;$ i is the ego, q and j are alters, $p_{iq} * m_{jq}$ measures the portion of i's relationships with j that is redundant to i's relationships with other alters (Burt, 2009; Dhand et al., 2016). Ties are weighted as strong or weak relationships as evaluated by the respondents.

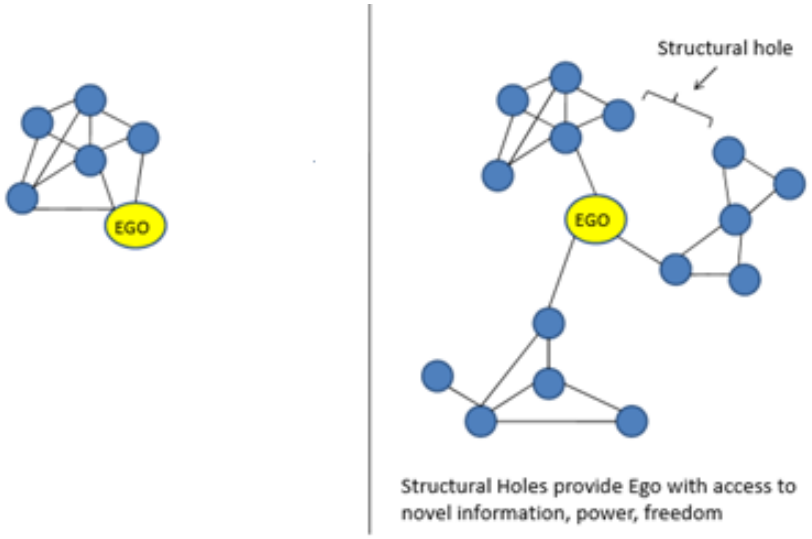


Figure 12: Structural holes facilitates egos with novel information and awareness

A relatively higher value of effective size is a measure of relatively higher structure holes present in a personal network. Higher structural holes in a personal network increases the likelihood of the ego to have access to greater social resources, better opportunities to operationalize social capital, and to receive novel information, awareness, and knowledge (Burt, 2001, 2009). These egos, who have relatively higher structural holes (i.e. a relatively higher effective size) have a higher likelihood to adopt and integrate social innovation (such as cleaner cooking systems) in their routine practices (Burt, 2001, 2009; O'malley et al., 2012).

To summarize the concepts of structural characteristics of a personal network data pertaining to structural holes: if we compare two personal network, a relatively higher effective size means

higher structural holes in that ego network, which increases the likelihood of diffusion of novel information to the corresponding ego (Burt, 2001, 2009).

Bivariate analyses for structural characteristics

Evaluation of network size, density, and structural holes of different groups of network data provides insight to social resources, which exist at the disposal of the egos, and their comparative likelihood to receive novel information or awareness in their communities. For each group of network data (LPG women, non-LPG women, LPG men, and non-LPG men), descriptive measures (mean, median, SD, and IQR) were computed for their structural characteristics (network size, network density, and effective size). This was followed by undertaking diagnostics tests for bivariate analyses. Depending on the diagnostic tests, parametric (Welch's t-test) or non-parametric (Mann Whitney U) test was conducted to compare the structural characteristics of the personal network data for these 4 groups (Chung, 2009). To examine the hypotheses for this aim of the study, bivariate analyses of structural characteristics was undertaken for: 1) LPG women vs. non-LPG women; and 2) LPG men vs. non-LPG men.

2. Composition analysis

In personal networks, composition analyses is undertaken to explore the characteristics of alters relative to the egos. In this study, using Krackhardt and Stern's E-I index (E-I index), the extent of homophily or heterophily of the personal networks was measured (Krackhardt & Stern, 1988). The E-I index measures the relative density of internal connections (same caste, gender, or LPG adoption status) an ego possesses compared to its external connections (other caste, gender, or LPG adoption status) within a social group (Krackhardt & Stern, 1988; McGrath & Krackhardt, 2003). The E-I index is a measure that focuses on ties between alters and ego, rather than the nodes. The E-I index for an ego is measured as:

$$\frac{E - I}{E + I}$$

Where E (external) is the number of ties to alters in different groups (relative to the ego such as other castes, gender, or LPG adoption status), I (internal) is the number of ties to alters of the same group (relative to the ego such as same caste as that of the ego, same gender, or LPG adoption status).

Aim 2 explored 4 groups of personal network data: 1) women from the case group households adopting LPG (LPG women); 2) men from the corresponding case group households adopting LPG (LPG men); 3) women from the control group households not adopting LPG (non-LPG women); 4) men from the corresponding control group households not adopting LPG (non-LPG men). The E-I index of three attributes was calculated in this study for each of the 4 groups of data: 1) gender; 2) caste; and 3) LPG adoption. Homophily or heterophily was determined by the value of the E-I index. The E-I index varies between the value -1 (absolute homophilic network) to +1 (absolute heterophilic network). For instance: for an LPG-women personal network, if all alters of the personal network of the respondent are women, then the E-I gender index for that network will be -1. If all alters of the network are men, then the E-I index for that network will be +1. For an LPG adopter household, if all alters of the network also own LPG, then the E-I index for LPG adoption for that network will be -1. However, if all the alters of that network are non-LPG adopters, the E-I LPG adoption index for that network will be +1.

Krackhardt and Stern (1988) opine that networks with a higher homophily facilitates egos to engage in a higher degree of social influence. This results in expedited diffusion of information between the ego and its alters. Barriers to information passage arising due to differences in attributes (different caste identities, genders, or class) are lower with more homophily in a personal network

(Krackhardt, 1992; Lozares, Verd, Cruz, & Barranco, 2014). When networks are more homophilic, social influence on egos from their alters increase.

Krackhardt and Stern (1988) invoke Granovetter (1983) and summarize the likelihood of dissemination of information within a homophilic or heterophilic personal network: 1) As personal networks tend to be more homophilic (closer to -1), information dissemination to egos is relatively easier; 2) As personal networks tend to be more homophilic (closer to -1), likelihood to act on the basis of this enhanced awareness also increases; 3) As personal networks tend to be more homophilic (closer to -1), egos' decisions tend to manifest behavior similar to her/his alters in her/his personal network.

Bivariate analyses for compositional characteristics

To examine the relative homophily in the personal network data of these 4 groups, bivariate analyses of compositional characteristics were conducted. Diagnostic tests preceded bivariate analyses to ascertain the type of bivariate analyses to be used: parametric (Welch's t-test) or non-parametric (Mann Whitney U) test (Chung, 2009). Bivariate analyses (LPG-women vs. non LPG-women, and LPG-men vs. non LPG-men) was undertaken to explore comparison of compositional characteristics (Chung, 2009). This facilitated testing of hypotheses for aim 2 of the study (Chung, 2009). The E-I index for three compositional characteristics that were compared are: 1) gender; 2) caste; 3) LPG adoption status of alters.

4.9 Concluding remarks

This chapter discussed the approach and methods adopted to undertake this study. The chapter discussed how the RE-AIM framework informed the conceptualization and analyses of the study. The chapter also discussed in detail the sampling strategy, the data collection, and the data analyses plan for the two aims of the study. The next chapter discusses the results for each of the two aims of the study.

V. Results

5.0 Organization of this chapter

Section 5.1 discusses the results of aim 1 (adoption) of this study. This section elaborates respectively: 1) univariate analyses; 2) bivariate analyses; 3) diagnostic tests for binomial regression; and 4) results of 5 binomial logistic regression models. Section 5.2 discusses the results of aim 2 (personal network analyses) of this study. This section discusses respectively: 1) structural characteristics, diagnostic tests for bivariate, and bivariate analyses of structural characteristics; and 2) compositional characteristics, diagnostic tests for bivariate, and bivariate analyses of compositional characteristics. Section 5.3 summarizes results against each of the hypotheses for aim 1 of the study while section 5.4 summarizes results against each of the hypotheses for aim 2 of the study. Section 5.5 concludes.

5.1 Results of aim 1 (adoption)

5.1.1 Univariate analyses

Appendix 4 (Table 7) provides description of the univariate characteristics of the sample (women respondents from each household, N=510) used to study aim 1. Univariate description of each of the variables used in the models is discussed below.

Outcome variable

LPG adoption

There was equal number of case and control group households. LPG adopters (case group) represented 50% (255 households) of the sample while non-LPG adopters (control group) represented the remaining 50% (255 households) of the sample.

Demographic control variables

Age

The average age of women respondents was 40.34 years (SD=13.32). The median value of age of the women respondents was 38 years. The interquartile range (IQR) was 19. The value of Shapiro Wilk's test for normality ($W=0.95$, $p<0.001$) was closer to unity suggesting a standard normal distribution. The data were moderately positively skewed (0.79). The standard accepted value of Pearson's measure of kurtosis for a standard normal distribution is equal to 3. Kurtosis of 3.17 (mesokurtic) closer to the standard accepted value for this data suggest a standard normal distribution. The age range of the sample was between 17 and 90 (both inclusive).

Marital status

More than two-third (87.25%) of the respondents reported being married. There were 12.16% of the respondents were widows, while only 0.58% of the respondents were unmarried.

Literacy of the respondent (women)

There were more than half (65.88%) of the respondents, who reported to being illiterate. There were 6.67% of women who reported to have completed primary education (till class 4). There were 13.53% of the respondents, who had completed their school education till class 8. There were 10.39% of the respondents, who had completed school education till class 10 while 1.96% of the respondents, who had completed high school education till class 12. Only 1.57% of the respondents had completed college education.

Literacy of the primary male decision maker of the household

There were 43.13% of the primary male decision makers, who had no education. There were 4.51% of the primary male decision makers, who had completed primary education till class 4. There were 23.53% of the households, who had completed school education till class 8, and 15.49% of the households, who had completed school education till class 10. There were 3.14% of the households,

who had completed high school till class 12, while only 4.12% of the households reported that their primary male decision makers have completed college. For 5.49% of the households, this data were not applicable. These were primarily those households, where women respondents were widows or unmarried. The study did not drop these households. It was crucial to explore the stove adoption behavior of these households as well.

Caste

There were 14.51% of the respondents, who belonged to general castes. There were 48.63% of the respondents, who belonged to the other backward castes (OBC), while 35.88% of the respondents reported as scheduled castes/scheduled tribes (SC/ST). Only 0.98% of the respondents belonged to religious minorities (predominantly Muslim households). The study followed the Government of India standard regulations on caste categorization for these regions.

Affordability related measures

Income (last month) of the respondent

Rather than inquiring on the average income of the respondent, the study collected data on the last month income of the respondent. The "last month" income means the income generated by the respondent (from outside of the household activities) during the month prior to when the survey was administered. The sample was selected based on the LPG adoption status within a year. Thus, it was more important to assess the recent income (if any) of the respondent than the average income over a certain period of time. These communities frequently grapple with unforeseen livelihood shocks, which vastly change their income patterns. Averaging incomes over these temporal patterns would have been less precise, and afflicted with recall bias.

The average value of the last month income of the respondent was INR 1056.09 (SD=1005.31). The median value of the last month income of the respondent was INR 1000. The IQR was INR 1350. The value of Shapiro-Wilk's test for normality ($W=0.87$, $p<0.001$) was closer to

unity. However, the data were positively skewed (1.06), and a high Pearson's measure of kurtosis of 7.39. The range of the sample was between INR 0 and INR 8000 (both inclusive). Due to deviations from normality, non-parametric Mann Whitney U test was conducted for bivariate analysis.

Membership of Self-Help Groups (SHGs)

There were 66.86% of the respondents, who reported membership with SHGs while 33.14% of the respondents reported that they did not belong to any SHG. These SHGs were created to elevate the economic status of women on a self-sustaining basis predominantly under the aegis of a prominent state poverty alleviation scheme known as the Development of Women and Children in Rural Areas (DWCRA) (Rajakutty & Kojima, 2002).

Income (last month) of the household

The average value of the last month income of the household was INR 2912.69 (SD=2270.64). The median value of the last month income of the household was INR 2600 (IQR=1000). The value of Shapiro-Wilk's test for normality ($W=0.62$, $p<0.001$). The data were positively skewed (5.25) with a high Pearson's measure of kurtosis of 50.37. The range of the sample was from INR 0 to INR 30000. Due to deviations from normality, non-parametric Mann Whitney U test was conducted for bivariate analysis.

Land ownership of the household

The average value of the land ownership of the household was 2.15 acres (SD=3.19). The median value of the land ownership of the household was 2 acres (IQR=2.5). The value of Shapiro-Wilk's test for normality ($W=0.48$, $p<0.001$) was not closer to unity suggesting deviations from normality. The data were positively skewed (8.58). The range of the sample was between 0 acres and 50 acres (both inclusive). Due to deviations from normality, non-parametric Mann Whitney U test was conducted for bivariate analysis.

Agricultural debt of the household

Agriculture is one of the primary occupations of these communities. Loan for agricultural activities is common in these communities. The average value of the agricultural debt of the household was INR 13,399.41 (SD=25789.99). The median value of the agricultural debt of the household was INR 0 (IQR=20000). The value of Shapiro-Wilk's test for normality (W=0.59, $p<0.001$). The data were positively skewed (2.17). The range of the sample was between INR 0 and INR 100000 (both inclusive). Due to deviations from normality, Mann Whitney U test was undertaken for bivariate analysis.

Accessibility related measures

Nearest tarmac road from the household

The average value of the distance to the nearest tarmac road from the household was 0.67 Kms (SD=0.98). The median value of the distance to the nearest tarmac road from the household was 0.4 Kms (IQR=0.9). The value of Shapiro-Wilk's test for normality (W=0.58, $p<0.001$). The data were positively skewed (6.77), and the range of the sample was between 0 Kms to 15 Kms (both inclusive). Due to deviations from normality, Mann Whitney U test was undertaken for bivariate analysis.

Nearest LPG distribution center from the household

The LPG cylinders are distributed through government registered distribution centers. Households have 2 options: 1) travel to these distribution centers and collect LPG cylinders; 2) pay for the home delivery of LPG cylinders. The average value of the distance to the nearest LPG distribution center from the household was 8.62 Kms (SD=4.73). The median value of the distance to the nearest LPG distribution center from the household was 9 Kms (IQR=6). The value of Shapiro-Wilk's test for normality (W=0.95, $p<0.05$) was closer to unity suggesting standard normal distribution. The data were slightly positively skewed (0.52) with a Pearson's measure of kurtosis as

2.45 (closer to accepted standard Pearson's kurtosis value of 3). The range of the sample value was between 0.25 Kms to 20 Kms.

Preference for smaller LPG cylinders

Substantial proportion of respondents (92.16%) reported that they would prefer smaller LPG cylinders to the current practice of 29.6 Kg (65.25 pound) weight of one LPG cylinder (fully filled with gas). This constitutes 14.6 Kg (32.18 pound) of gas and 15 Kg (33.06 pound) of the cylinder weight. Cylinders are made of cast iron. Only 1.37% respondents did not prefer smaller LPG cylinders, while 6.47% of the respondents had no directional opinion on this issue.

Availability of free biomass near the household

While the entire study sample had access to free biomass from the nearby forests, 87.25% of the respondents reported that availability of free biomass near the household did not deter LPG adoption. Only 12.75% households reported that availability of free biomass near their households deterred LPG adoption.

Distance to the biomass source

An additional factor in biomass availability issue is the distance to these biomass sources. Women, primarily shoulder the drudgery of collecting biomass from the nearby forests. The average value of the distance to the nearest biomass source from the household was 2.36 Kms (SD=1.37). . The median value of the distance to the nearest biomass source from the household was 2 Kms (IQR=1.5). The value of Shapiro-Wilk's test for normality ($W=0.83$, $p<0.001$) was closer to unity. However, the data were positively skewed (2.04) with a high Pearson's measure of kurtosis as 11. The range of the sample value was between 0 Kms to 10 Kms. Due to deviations of this measure from normality, Mann Whitney U test was conducted for bivariate analysis.

Decision making capacity of women to purchase new stove

There were 46.27% of the respondents (women), who reported that the decision to purchase a new stove rests with their spouse, as against 28.82% of the respondents, who reported that the decision rests with them. There were 20.20% of the respondents (women), who reported that it was a mutual endeavor, while 0.98% reported that it was a collective decision involving other family members as well in addition to the respondent and the spouse of the respondent. There were 1.76% of the respondents, who reported that the decision to buy a new stove rests solely on other family members with no deliberation from the respondent or the spouse of the respondent.

Awareness related measures

Perception of LPG safety on adoption

Perception of LPG safety on adoption was measured by examining if the possibility of explosion of LPG cylinders influenced their adoption decision. There were 91.18% of the respondents, who reported that scattered rumors and their own perception on LPG cylinder explosion did not deter them from adoption of LPG cooking systems. Anecdotal evidence suggests that perception of a possibility of LPG cylinder explosion is a significant factor impacting choices of the rural poor communities to initially adopt LPG stoves. Numerous campaigns have included this issue as central to their dissemination of awareness endeavor. In these communities, 8.82% respondents in the sample felt that the danger of LPG explosion contributed in their non-adoption of LPG cooking systems.

LPG adoption against household traditional culture

Cultural constraints deter some households in rural communities from cooking food using fuel other than wood, biomass, or dung cakes (Bailis, Cowan, Berrueta, & Masera, 2009). There were 95.88% of the respondents, who reported that adoption of LPG was not against their traditional household cultures of cooking practices. In the sample, only 1.18% of the respondents mentioned

that LPG adoption was against their traditional cooking culture, while 2.94% of the respondents had no directional opinion on this issue.

LPG adoption enhance social status

Social status in rural communities is determined by new possessions in their respective households such as new technological innovations including LPG cooking systems (Bhojvaid et al., 2014). There were 98.24% of the respondents, who believed that LPG adoption enhances their social status in their respective communities. Remaining 1.76% of the respondents did not hold this view.

Awareness campaigns attended

There were 92.16% of the respondents, who had attended at least one in-person awareness campaign on LPG adoption and use organized by the SHGs, government, oil marketing companies, or Gram Panchayats (village level self-governments). They are mostly arranged by government institutions or public private collaborating units. These campaigns did not include awareness generated via media channels such as TV or radio. Only 7.84% of the respondents had not attended any campaign on LPG adoption and use.

5.1.2 Bivariate analyses

Bivariate association between the outcome variable, LPG adoption (yes/no) and independent variables in the sample are discussed as follows. Bivariate results are shown in appendix 4 (Table 8-Table 10).

Association between LPG adoption and demographic predictors

Age

There was a statistically significant difference in the mean age of the women respondents between LPG adopters group and non-LPG adopters group (t=-2.69, p=0.007). The mean value of the age of the LPG adopter respondents was 38.75 years (SD=11.64), while it was 41.92 (SD=14.69)

for non-adopters. Lower age groups seemed to be LPG adopters, while older age groups seemed to be non-adopters.

Marital status

The marital status distribution of the respondents was fairly balanced. Around 89% of the LPG adopters were married compared to 85% of the non-LPG adopters, who were married. There were 0.39% of LPG adopters, who were unmarried while 0.78% of the non-LPG adopters, who were unmarried. There were 10% of the LPG adopters, who were widows compared to 14% of non-LPG adopters, who were widows. There was no statistically significant association between the marital status of the respondents and their LPG adoption status ($\chi^2 = 2.21$, $p=0.33$).

Highest level of education completed

More than half of the respondents in both the groups had not received any education. There were 61.57% of LPG adopters, who had no education compared to that of 70.20% of non-LPG adopters. There were 2.75% of LPG adopters, who had completed high schools. This percentage dropped to 1.18% for non-LPG adopters. Only around 1.5% of LPG adopter respondents had completed college education. The proportion was similar for non-LPG adopters, where only 1.5% of respondents had completed college education ($\chi^2 = 12.44$, $p=0.03$).

Highest education of male decision maker

Almost 41.57% of the LPG adopters represented households, whose male decision makers had no education compared to 45.88% in the non-LPG adopters group. There were 3.53% of LPG adopters respondents represented households, where their male decision makers had completed high school. This value dropped to 2.74% for the non-LPG adopter group. Only around 5.09% of LPG adopter respondents had their male decision makers who completed college education. This value dropped to 3.14% for the male decision makers from the non-LPG adopter group ($\chi^2 = 13.96$, $p=0.03$).

Caste

There were 60.78% of the LPG adopter respondents, who belonged to OBC caste. There were 36.47% of the respondents from the non-LPG adopter group belonged to OBC caste. There were 21.17% of the respondents from the LPG adopter group represented the General caste while 7.84% of the respondents from the non-LPG adopter group represented the General caste. Only 17.25% of the respondents from the LPG adopters represented the SC/ST caste group. However, 54.50% of the respondents from the non-LPG adopters represented the SC/ST caste group. ($\chi^2 = 80.63$, $p<0.001$).

Association between LPG adoption and affordability related predictors

Income (last month) of the respondent

Recurring studies have shown that income presents a critical factor in driving households to adopt cleaner cooking systems (Lewis & Pattanayak, 2012). The findings showed that the median value of the income of the respondents from the LPG adopter group was around INR 1100 (IQR=1025). The median value significantly dropped to INR 750 (IQR=1350) for non-LPG respondents ($w=198390$, $p<0.001$).

Membership of SHGs

Studies have shown that formal community groups (especially of women) influence the adoption of cleaner cooking systems in these energy poor households (Lewis & Pattanayak, 2012). The findings showed that 71% of the LPG adopter respondents belonged to an SHG. The value significantly dropped for non-LPG respondents. There were 63% non-LPG respondents, who belonged to SHGs. While 29% LPG adopters had no SHG affiliation, almost 36% of the non-LPG adopters had no SHG affiliation ($\chi^2 = 2.87$, $p<0.001$).

Income (last month) of the household

The findings showed that the median value of income of the LPG adopter households was INR 3000 (IQR=2000). The median value of income dropped for the non-LPG adopter households to INR 2000 (IQR=1500) (w=256530, p<0.001).

Land ownership of the household

There was a statistically significant association between amount of land owned by the households and LPG adoption. The median value of the land owned by LPG adopter households was 2 acres (IQR=3), and 1 acre (IQR=2) for non-LPG adopter households. (w=140250, p<0.001).

Agricultural debt owed by the household

There was a statistically significant association between agricultural debt and LPG adoption. The mean value of the agricultural debt owed (at the time of the data collection) by the LPG adopter households was INR 19,179 (SD=30,635.10). This value dropped to INR 7619 (SD=18160.06) for non-LPG adopter households. The median value of the agricultural debt owed by LPG adopter households was 0 (IQR=0), and 0 acre (IQR=30000) for non-LPG adopter households (w=81090, p<0.001).

Association between LPG adoption and accessibility related predictors

Nearest tarmac road from the household

Sustained adoption of LPG cooking systems depends on consistent and on time supply of LPG cylinders to consumers. Infrastructural facilities especially tarmac roads are crucial in impacting demand and supply of LPG. Findings showed a significant association between the distance of the nearest tarmac road with LPG adoption by the respondents (w=41692.5, p<0.001). The median value of the distance to the nearest tarmac road from the LPG adopter households was 0.2 Kms (IQR=0.4), while the median value of the distance to the nearest tarmac road from the non-LPG adopter households was 0.5 Kms (IQR=1.05).

Nearest LPG distribution center

The findings showed that there was a significant association between the distance to the nearest LPG distribution center and adoption of LPG by the respondents (t=-2.17, p=0.03). The mean value of the distance to the nearest LPG distribution center for the households which adopted LPG was 8.16 Kms, while the value increased to 9.07 Kms for non-LPG adopter households.

Preference for smaller LPG cylinders

With infrastructural bottlenecks, transportation of a 29.6 cast iron LPG cylinder has always been an issue for the poor, especially for those living in rural interiors. However, the findings showed that rural poor households still prefer the existing size of the cylinders to smaller cylinders. Almost 97% of LPG adopters and almost 87% of non-LPG adopters preferred the existing size of LPG cylinders. Only 0.78% of LPG adopters and 1.96% of non-LPG adopters preferred to have smaller LPG cylinders. There were 1.96% of LPG adopters and 10.98% of non-LPG adopters, who had no opinion on the size of the LPG cylinders ($\chi^2 = 18.75$, $p<0.001$).

Availability of free biomass near the household

Almost 99% of LPG adopters and 75% of non-LPG adopters mentioned that availability of free biomass did not deter them from adopting cleaner cooking systems. It was interesting to note that while only 0.78% of LPG adopters mentioned that availability of free biomass deterred adoption of cleaner cooking systems, the percentage significantly increased to 24% of non-LPG adopters, who mentioned that availability of free biomass deterred clean cooking adoption ($\chi^2 = 63.47$, $p<0.001$).

Distance to the biomass source

The findings showed that there was no significant bivariate association between distance to the biomass source from the household and LPG adoption (w=185512, p=0.71). The median distance to the biomass source from the LPG adopter households was 2 Kms (IQR=1.5), and the median distance to the biomass source from the non-LPG adopter households was also 2 Kms (IQR=1.5).

Decision making capacity to purchase new stove

In a rural poor patriarchal society, decision making status is distributed among different family members. This distribution is a function of the areas, where a decision is required. It was thus crucial to explore who decides on the purchase of a new stove. Almost 45.88% of the respondents (women) from the LPG adopter group and 46.66% of the respondents (women) from the non-LPG adopter group mentioned that it was their spouse (husbands), who decide on purchasing of the new stoves. Only 29% of the respondents from the LPG adopter group and 28% of the respondents from the non-LPG adopter group replied that the decision rests solely on them to purchase a new stove. Almost 18.82% LPG adopters mentioned that it would be a mutual decision while the value went up to 21% for non-LPG adopters. There was no significant association between the decision making capacity to purchase new stove and LPG adoption ($\chi^2 = 2.87$, $p<0.72$).

Association between LPG adoption and awareness related predictors

Safety of LPG cylinders on adoption

Safety of LPG cylinders was measured by examining if the perception on possibility of explosion of LPG cylinders influenced adoption decision. Almost 98% respondents from the LPG adopters group did not feel that possibility of LPG cylinder explosion was a critical factor that impacted their adoption. This value dropped to 84.31% of the respondents from the non-LPG adopters group. Only 1.96% of the respondents from the LPG adopters group felt that the possibility of the LPG explosion is a critical factor that did impact their adoption. It was interesting

that this value rose to 15.69% of the respondents from the non-LPG adopters group. In other words, almost 15.69% of the non-LPG adopters felt that the possibility of LPG explosion was a critical factor impacting their adoption ($\chi^2 = 28.17$, $p<0.001$).

LPG against household traditional culture

The majority of the respondents from both groups felt that cooking on LPG was not against their traditional culture. Almost 95% of LPG adopters and 96.8% of non-LPG adopters believed that LPG was not against their traditional cooking practices. Only 0.39% of LPG adopters and 1.96% of non-LPG adopters believed that adopting and using LPG for cooking were not confirm with their traditional practices ($\chi^2 = 8.12$, $p=0.01$).

LPG enhance social status

The findings suggested that there was no significant difference in adoption behavior of respondents with social status from LPG uptake. Majority of the respondents from both the LPG adopters and non-adopters' group felt that adoption of LPG enhances social status in their habitations. Almost 99% of adopters and 97% of non-adopters felt that LPG enhances social status in their habitations. Only 0.78% of adopters and 2.78% of non-adopters felt that social status was not impacted by LPG adoption ($\chi^2 = 1.81$, $p=0.18$).

Campaigns attended

The findings suggested that there was a significant difference in the LPG adoption status of the respondents determined by their exposure to awareness campaigns ($\chi^2 = 16.96$, $p<0.001$). Almost 87.05% LPG adopters had not attended any campaign. However, this value rose to 97.25% for non-LPG respondents. Similarly, almost 12.94% of the LPG adopters had attended at least one awareness campaign. Similarly, 2.74% of the non-LPG adopters had attended at least one awareness campaign on LPG adoption and use.

5.1.3 Diagnostic tests for binomial logistic regression models

Each of the responses in the sample was mutually exclusive, independent, and exhaustive. The minimum number of observations for each of the variables used in the regression models was way higher than the least required value of 50, as can be seen from univariate table in appendix 4, Table 7. Bivariate analysis from appendix 4, Table 8-Table 10 showed that statistically significant association existed between multiple predictors with the outcome variable. The set of predictors controlled for in the regression models were either continuous or categorical, while the outcome variable was nominal. There was no multicollinearity issues in any of the models 1 through 5 as none of the predictors in any of these regression models had the VIF values of higher than 4 (appendix 4, Table 11-Table 15). The Hosmer & Lemeshow goodness of fit tests were statistically non-significant for all the models 1 through 5 (appendix 4, Table 16). The ROC curves were plotted for each of the models (appendix 4, Figure 24-Figure 28). Area under the ROC curves for each of the models 1 through 5 was higher than 0.70 (normally accepted value). Values from the Hosmer & Lemeshow test (all non-significant) and the ROC curves (all higher than 0.70) validated that the regression models 1 through 5 were stable and fitting the data.

5.1.4 Results of the binomial logistic regression models

Five binomial regression models predicting adoption of LPG (women respondents from each household, N=510) are discussed as follows (refer Table 4 for the predictors and reference categories). **Model 1** controlled only for the demographic predictor variables. Controlling for these demographic predictors, **model 2** examined the relative contribution of measures pertaining to affordability of the respondents. Controlling for these demographic predictors, **model 3** examined the relative contribution of measures pertaining to accessibility of the respondents. Similarly, controlling for these demographic predictors, **model 4** examined the relative contribution of measures pertaining to awareness of the respondents. Controlling for these demographic predictors,

model 5 examined the relative contribution of measures pertaining to affordability, accessibility and awareness of the respondents. As discussed earlier, this study tested the concurrent impact of the measures pertaining to affordability, accessibility, and awareness (3As) on LPG adoption. In other words, the study examined the relative contribution of each of the measures of the 3As, when all of the measures pertaining to 3As are controlled for in a model. Model 5 controls for all the variables hypothesized to explore research aim 1. This model was central to the analyses for aim 1. The discussion and analyses was also supported by model 2, model 3, and model 4 to explore the independent effects of affordability, accessibility, and awareness of LPG adoption. Table 5 summarizes the characteristics of these 5 regression models.

Table 4: List of variables and reference categories for aim 1

Outcome Variable for aim 1	**Codes**
LPG Adoption	Yes/No®
Demographic predictor variables	**Codes**
Age	Years
Marital Status	Married/Unmarried®/Widow/Divorced
Literacy: Highest level of education completed	None ®/Below or up to class 4/Class 5 to class 8/ Class 9 to class 10/ Class 11 to class 12/College
Literacy: Highest education of male decision maker	None®/Below or up to class 4/Class 5 to class 8/ Class 9 to class 10/ Class 11 to class 12/College/Not Applicable
Caste	General®/Other Backward Castes (OBC)/Scheduled Castes/Scheduled Tribes [SC/ST]/Other religious minorities/Others
Affordability related predictor variables	**Codes**
Last month income of the respondent	Indian National Rupee (INR)
Membership of Self-Help Groups (SHGs)	Yes/No®
Last month income of the household	Indian National Rupee (INR)
Land ownership of the household	Acres
Agricultural debt owed by the household	Indian National Rupee (INR)
Accessibility related predictor variables	**Codes**
Nearest tarmac road from the household	Kilometers (Km)
Nearest LPG distribution center	Kilometers (Km)

Preference for smaller LPG cylinders	Yes/No®/Can't say
Availability of free biomass near the household	Yes/No®/Can't say
Distance of the biomass source	Kilometers (Km)
Decision making capacity to purchase new stove	Respondent®/Spouse of respondent/Respondent and spouse of the respondent/Respondent, spouse of the respondent, and others/Respondent and other but not the spouse/Others but not the respondent or the spouse of the respondent
Awareness related predictor variables	**Codes**
Perception of LPG explosion on adoption	Yes/No®/Can't say
LPG against household traditional culture	Yes/No®/Can't say
LPG enhance social status	Yes/No®/Can't say
Campaigns attended	Yes®/No

®Reference category

Table 5: Summary of 5 binomial regression models for aim 1

Model nos.	Model Labels	Predictors controlled
Model 1	Control	Demographic predictors
Model 2	Affordability	Demographic predictors, affordability
Model 3	Accessibility	Demographic predictors, accessibility
Model 4	Awareness	Demographic predictors, awareness
Model 5	Affordability+Accessibility+Awareness (3As)	Demographic predictors, affordability, accessibility, awareness

Model 1 (Demographic predictors)

Model 1 tested the extent to which only the demographic variables impact the variation in the status of LPG adoption by the sample respondents.

Age had a statistically significant association with LPG adoption. Controlling for all other variables in the model, with a one year increase in age of the respondents (women) the predicted odds of adoption of LPG dropped by 3%. In other words, controlling for all other variables, with every one year increase in age of the respondents, the predicted odds of not adopting an LPG by the respondents was 1.03 times more than adopting an LPG by the respondents (OR=0.97, CI: 0.95-

0.99). SC/ST caste group had a statistically significant association with adoption of LPG. Controlling for all other demographic predictors, the predicted odds for SC/ST caste respondents were 89% lower than the General caste respondents to adopt LPG (OR=0.11, CI: 0.05-0.20). In other words, controlling for all other demographic predictors, General caste respondents were 9.09 times more likely to own an LPG than the SC/ST respondents. OBC castes and other religious minorities were not significantly associated.

Marital status, literacy of the women respondents, literacy of male household decision makers showed no significant association. The AIC for model 1 was 635.64. McFadden's R square for model 1 was 0.15.

Model 2 (Affordability)

Model 2 tested the extent to which the affordability related characteristics impacted the disparity in adoption of LPG by the respondents, after controlling for the demographic predictors.

Income (last month) of the respondents and total income (last month) of the corresponding households were weakly associated with LPG adoption. With every one unit increase in income of the respondents, the predicted odds of adopting LPG increased by only 0.02%, after controlling for the demographic predictors (OR=1.0002, CI: 1.00009-1.0004). Similarly, with every one unit increase in total income of the households, the predicted odds of adopting LPG increased by only 0.03%, after controlling for the demographic predictors (OR=1.0003, CI: 1.0001-1.0004).

Membership with SHGs had a significant association with LPG adoption. Controlling for the demographic predictors, the predicted odds of the respondents who were members of an SHG was 81% higher to adopt LPG than the respondents who held no SHG memberships (OR=1.81, CI: 1.16-2.86). In other words, after controlling for demographic variables, SHG members were 1.81 times more likely to adopt LPG than the non SHG members.

Agricultural debt had a weak association with LPG adoption. Controlling for the demographic predictors, the predicted odds of households with agricultural debt to adopt LPG was only 0.001% more than the households with no agricultural debt (OR=1.00001, CI: 1.00e+00 - 1.00e+00).

Land ownership of households was not significant. The demographic predictors controlled for in this model showed consistency with that in model 1. The predicted odds of SC/ST caste respondents to adopt LPG were 87% lower than the General caste respondents (OR=0.13, CI: 0.06-0.27). OBCs and religious minorities were not significant. Literacy of the respondents, literacy of male decision makers, and marital status was not significant. Also, age was not significantly associated in this model, unlike model 1. The AIC for model 2 was 599.19. McFadden's R square for model 2 was 0.22.

Model 3 (Accessibility)

Model 3 tested the extent to which the accessibility related characteristics impacted the variation in adoption of LPG status of the respondents, after controlling for the demographic predictors.

Controlling for all the demographic predictors, with every one Kilometer (Km) increase in the distance to the nearest tarmac road from the respondents' household, there was a 27% drop in the predicted odds to adopt LPG by the respondents (OR=0.73, CI: 0.54-0.89). In other words, with every one Km increase in the distance to the tarmac road from the respondents' households, the predicted odds of non-adoption of LPG were 1.36 times higher than LPG adoption.

Controlling for all the demographic predictors, respondents who felt that free availability of biomass deter clean stove adoption were 99.98% less likely to adopt LPG (OR=0.02, CI: 0.003-0.007). In other words, respondents who felt that free availability of biomass does not deter adoption of clean cooking systems were 50 times more likely to adopt LPG.

Controlling for all the demographic predictors, with every one Km increase in the distance of the biomass source from the respondents' household, there was an 18% increase in the predicted odds to adopt LPG by the respondents (OR=1.18, CI: 1.01-1.39). In other words, controlling for all the demographic predictors, the odds of the respondents adopting LPG was 1.18 times more than the respondents not adopting LPG with every one Km increase in the distance to the biomass source.

The distance to the nearest LPG distribution center, preference for smaller LPG cylinders, and the decision-making capacity to purchase new stoves were not associated with LPG adoption. Similar to model 1 and model 2, caste as a demographic control variable was significant in this model too. Controlling for all other variables in the model, the predicted odds for SC/STs to adopt LPG was 99.92% lower than the General caste groups (OR=0.08, CI: 0.04-0.18). Age, marital status, and literacy of the respondent were not significantly associated. The AIC for model 3 was 565.26. McFadden's R square for model 3 was 0.28.

Model 4 (Awareness)

Model 4 tested the relative contribution of the awareness related measures on the variation in the adoption of LPG, while controlling for the demographic variables.

Controlling for the demographic predictors, the predicted odds to adopt LPG for the respondents who perceived that LPG explosion as a contributing factor to base their decisions about LPG adoption was 93% lower, compared to those respondents who did not perceive this possibility as a contributing factor towards making adoption choices (OR=0.07, CI: 0.02-0.17). Controlling for the demographic predictors, respondents who believed that use of LPG did not fit their traditional cooking culture were 91% less likely to adopt LPG, than the respondents who did not believe that use of LPG is against their traditional culture (OR=0.09, CI: 0.004-0.72). However,

there was no significant association between respondents who did not hold any opinion on LPG impacting their traditional culture with their corresponding LPG adoption status.

Controlling for the demographic predictors, respondents who felt that LPG enhances their social status were 7.02 times more likely to adopt LPG than the respondents who did not feel that LPG would enhance their social status (OR=7.02, CI: 1.14-60.84). In other words, respondents who felt that adoption of LPG brings honor to their households in their respective communities were 602% more likely to adopt LPG than those households who felt that adoption of LPG is not related to enhanced status of their households in their respective communities, while controlling for the demographic predictors.

Controlling for the demographic predictors, respondents who attended at least one campaign on LPG adoption and use were 6.23 times more likely to adopt LPG than the respondents who did not attend any campaign on LPG adoption and use (OR=6.23, CI: 2.49-17.75).
Similar to model 1, model 2, model 3, caste as a demographic control variable was significant in this model too. Controlling for all other variables in the model, the predicted odds of SC/ST caste groups to adopt LPG was 91% lower than the General caste groups (OR=0.09, CI: 0.04-0.18). With every one year increase in age of the respondents, the predicted odds of LPG adoption dropped by 3% (OR=0.97, CI: 0.95-0.99). Literacy status of respondents and marital status of respondents were not significantly associated. The AIC for model 4 was 575.26. McFadden's R square for model 4 was 0.25.

Model 5 (Affordability+Accessibility+Awareness (3As))

Model 5 tested the relative contribution of the affordability, accessibility, and awareness related characteristics to the variation in adoption of LPG status of the respondents, after controlling for the demographic predictors.

Consistent with model 2 (affordability), income (last month) of the respondents and total income (last month) of the corresponding households were weakly associated with LPG adoption in this model. With every one unit increase in income of the respondents, the predicted odds of adopting LPG increased by only 0.06%, after controlling for accessibility, awareness, and demographic predictors (OR=1.0006, CI: 1.0003-1.0009). Similarly, with every one unit increase in total income of the households, the predicted odds of adopting LPG increased by only 0.02%, while controlling for accessibility, awareness, and demographic predictors (OR=1.0002, CI: 1.00003-1.0009).

Consistent with model 2 (affordability), agricultural debt also had a weak association with LPG adoption. Controlling for the accessibility, awareness, and demographic predictors, with every one unit increase in the agricultural debt, the predicted odds for households to adopt an LPG increased by only 0.002% (OR=1.00002, CI: 1.00e+00 - 1.00e+00).

Land ownership of households and membership of SHGs had no significant association with adoption of LPG.

Consistent with model 3 (accessibility), controlling for the affordability, awareness, and demographic predictors, with every one Km increase in the distance to the nearest tarmac road from the respondents' household, there was a drop of the predicted odds by 26% to adopt LPG by the respondents (OR=0.74, CI: 0.57-0.96). In other words, with every one Km increase in the distance of the tarmac road from the respondents' households, the predicted odds of non-adoption of LPG was 1.35 times higher than LPG adoption, while controlling for the affordability, awareness, and demographic predictors.

Controlling for the affordability, awareness, and demographic predictors, the predicted odds for respondents who felt that free availability of biomass deter clean stove adoption was 99.99% lower than the respondents, who felt that free availability of biomass does not impact clean stove

adoption, to adopt LPG (OR=0.01, CI:7e-4 – 3.3e-02). In other words, respondents who felt that free availability of biomass does not deter adoption of clean cooking systems were 166.6 times more likely to own an LPG stove than respondents who felt that free biomass availability deter adoption. Controlling for the affordability, awareness, and demographic predictors, with every one Km increase in the distance to the biomass source from the respondents' household, the predicted odds to adopt LPG increased by 20% (OR=1.20, CI: 1.00-1.44). In other words, controlling for the affordability, awareness, and demographic predictors, the predicted odds of the respondents adopting LPG was 1.20 times more than the respondents not adopting LPG, with every one Km increase in the distance of the biomass source.

Consistent with model 3 (accessibility), preference for smaller LPG cylinders, distance to the nearest LPG distribution center, and the decision-making capacity to purchase new stoves were not associated with LPG adoption.

Consistent with model 4 (awareness), controlling for the demographic, affordability, and accessibility predictors, the predicted odds of the respondents who perceived LPG explosion as a contributing factor influencing decisions on LPG ownership were 89% lower to adopt LPG, compared to those respondents who did not perceive LPG explosion as a contributing factor towards making adoption choices (OR=0.11, CI: 0.03-0.3). In other words, households which were scared that LPG cylinder could explode causing household damage did not adopt LPG.

Attending awareness campaigns were strongly associated with LPG adoption in the study sample. Controlling for the demographic, affordability, and accessibility related measures, respondents who attended at least one campaign on LPG adoption and use were 17.51 times more likely to adopt LPG than the respondents who did not attend any campaign on LPG adoption and use (OR=17.51, CI: 4.09-122.25).

Unlike model 4, there was no significant association between LPG adopters and respondents' belief in LPG adoption as against their traditional cooking practices. Similarly, there was no significant association between LPG adopters and respondents' perception of LPG enhancing their social status.

Similar to model 1, model 2, model 3, and model 4, caste as a demographic control variable was significant in this model. Controlling for all other variables in the model, the predicted odds of SC/ST caste groups to adopt LPG was 89% lower than the General caste groups (OR=0.11, CI: 0.04-0.2). OBC caste groups and other religious minorities had no significant association with LPG adoption. Age, literacy status of respondents, and marital status were not significantly associated with LPG adoption. The AIC for model 5 was 484.42. McFadden's R square for model 5 was 0.43.

Model comparison

AIC values helped in the selection of the most parsimonious and fitted model, which minimizes the Kullback-Leibler distance between a model and its actual data. Model 5 (3As) with lowest AIC value (484.42) was the most stable and fitted model. McFadden's R square showed the predictive capacity of the model in terms of how closely the models were fitted with the actual data. Among models 1 through 5, model 5 had the highest McFadden's R square value of 0.43. Also, the area under curve (C statistic) for model 5 was the highest with a value of 88%. Concluding from the AIC, the McFadden's R square values, and the C statistic, model 5 thus has been central to the discussion and analysis of aim 1, with occasional references to model 1-4.

5.2 Results of aim 2 (personal network analysis)

Four groups of personal network data were analyzed for this aim: 1) women from the case group households adopting LPG (LPG women); 2) women from the control group households not adopting LPG (non-LPG women); 3) men from the corresponding case group households adopting LPG (LPG men); and 4) men from the corresponding control group households not adopting LPG

(non-LPG men). The study was planned to collect network data from 100 women and 100 men (preferably spouse or primary male decision maker of the household) from 100 case households. Similarly, the target was to collect network data from 100 women and 100 men (preferably spouse or primary male decision maker of the household) from 100 control households. The final tally of data that could be collected was: 1) 100 women and 82 men from case households; and 2) 97 women and 82 men from control households. Reduction in the collected sample from original planned sample size was due to: 1) hesitation of few participants to provide data about their social networks; 2) migration of a few participants (especially men from the selected households) to nearby urban centers for livelihood activities. Structural and composition analyses preceded diagnostic tests and bivariate analyses for the collected network data.

5.2.1 Analyses of structural characteristics

Appendix 5, Table 18 shows the mean, median, standard deviation (SD), and interquartile range (IQR) values of structural characteristics (network size, network density, and effective size) of 4 groups (LPG women, non-LPG women, LPG men, non-LPG men) of the personal network data. Two sets of bivariate analyses between: 1) LPG women and non-LPG women; and 2) LPG men and non-LPG men, were undertaken to explore significant differences in their structural characteristics. The following diagnostic tests were conducted prior to undertaking bivariate analyses:

a. The responses were independent, mutually exclusive and exhaustive.
b. The dependent variables were continuous (interval/ratio) while the independent variables were nominal.
c. Variance of network size, network density, and effective size among the groups, which were to be tested, was homogeneous.
d. The distribution of network size, network density, and effective size among the groups was normal.

e. The minimum number of group size was 50.

Assumptions a, b, c, and e were met by all the measures (network size, network density, and effective size) of structural characteristics. To explore assumptions of normality, values of Shapiro-Wilk's test, skewness, and kurtosis were analyzed for each of these measures (appendix 5, Table 19). Welch's independents samples t-test was conducted when all assumptions for a parametric t-test was met. Mann Whitney U test, a routinely used non parametric test for network analyses, which tests whether the medians of two groups are equal, was conducted when there were deviations from assumptions of normality (Büttner, Scheffler, Czycholl, & Krieter, 2015).

Bivariate analyses of structural characteristics between LPG women and non-LPG women

Appendix 5, Table 20 shows the bivariate analyses of the structural characteristics of personal network data of LPG women and non-LPG women.

Network size

Welch's t-test was conducted to examine a significant difference in the network size between women respondents of LPG adopter households (LPG women) and women respondents of non-LPG adopter households (non-LPG women). There was no statistically significant difference in the mean value of the network size between the two groups of LPG women and non-LPG women ($t=-0.73$, $p=0.46$). The mean value of the network size for LPG women was 5.96 (SD=2.23), while the mean value of the network size for non-LPG women was 6.31 (SD=1.18).

Network density

Mann Whitney U test was conducted to test a significant difference in the network density between LPG women and non-LPG women. There was a statistically significant difference in the median value of the network density between the two groups of LPG women and non-LPG women (2755, $p<0.01$). The median value of the network density for LPG women was 1 (IQR=0.02), while that of non-LPG women was 1 (IQR=0).

Effective size

Welch's t-test test was conducted to test a significant difference in mean value of the effective size of ego network of LPG women and non-LPG women. There was no statistically significant difference in the mean value of the effective size between the ego networks of LPG women and non-LPG women (t=0.34, p=0.73). The mean value of the effective size of ego networks of LPG women was 1.35 (SD=0.63). The mean value of the effective size of the ego networks of non-LPG women was 1.30 (SD=0.61). No significant difference in effective size between LPG women and non-LPG women suggests that there was no significant difference in structural holes present in the ego networks of LPG women compared to that of non-LPG women.

Bivariate analyses of structural characteristics between LPG men and non-LPG men

Appendix 5, Table 20 shows the bivariate analyses of the structural characteristics of personal network data of LPG men and non-LPG men.

Network size

Welch's independent samples t-test was conducted to examine a significant difference in the network size between men respondents of LPG adopter households (LPG men) and men respondents of non-LPG adopter households (non-LPG men). There was no significant difference in the mean value of the network size between the two groups of LPG men and non-LPG men (t=-1.01, p=0.31). The mean value of the network size for LPG men was 6.06 (SD=1.44). The mean value of the network size for non-LPG men was 6.25 (SD=0.98).

Network density

Mann Whitney U test was conducted to examine if there was a significant difference in the median value of the network density between LPG men and non-LPG men. There was no significant difference in the median value of the network density between these two groups

(w=3329, p=0.82). The median value of the network density for LPG men was 1.00 (IQR=0), and that of the non-LPG men was also 1.00 (IQR=0).

Effective size

Welch's independent samples t-test was conducted to examine if there was a significant difference in mean values of the effective size of ego networks of LPG men and non-LPG men. There was a statistically significant difference in the mean value of the effective size between the ego networks of LPG men and non-LPG men (t=2.02, p=0.04). The mean value of the effective size of ego networks of LPG men was 1.29 (SD=0.61). The mean value of the effective size of the ego networks of non-LPG men was 1.11 (SD=0.40). It could be observed that there was a statistically significant difference in the mean value of effective size of the ego networks of LPG men and of non-LPG men. Higher mean value of effective size in LPG men indicates a relatively higher average number of structural holes in the ego networks of LPG men compared to that of non-LPG men. For a visual conception, Figure 13 shows an actual ego network from the data. The figure exhibits significant difference in the number of structural holes in the LPG men respondents and non-LPG men respondents

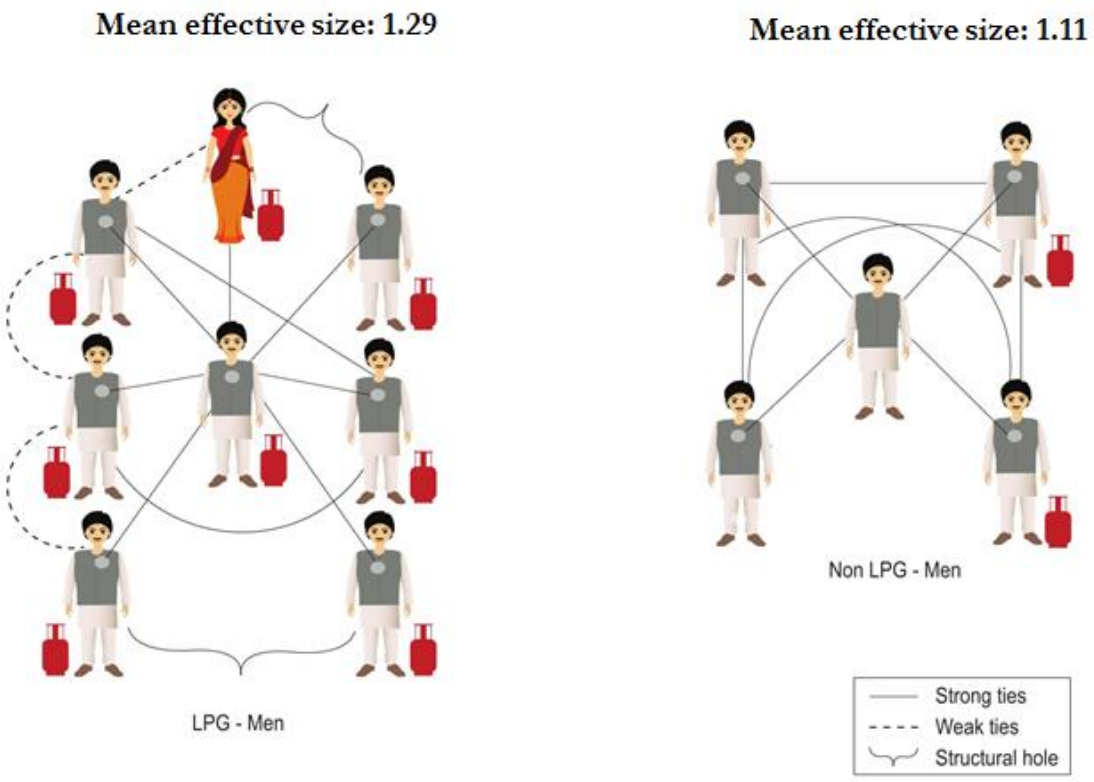


Figure 13: Mean effective size for LPG men respondents and non-LPG men respondents

5.2.2 Analyses of compositional characteristics

Appendix 5, Table 21 summarizes the mean, median, standard deviation (SD), and IQR of compositional characteristics (E-I index for caste, gender, and LPG adoption status) of 4 groups (LPG women, non-LPG women, LPG men, non-LPG men) of the personal network data. Bivariate analyses were conducted between: 1) LPG women and non-LPG women; and 2) LPG men and non-LPG men, to examine significant differences in the compositional characteristics. Following diagnostic tests were conducted prior to undertaking bivariate analyses:

a. The responses were independent, mutually exclusive and exhaustive.
b. The dependent variables were continuous (interval/ratio) while the independent variables were nominal.
c. Variance in E-I index for caste, gender, and LPG adoption status among these 4 groups, which were to be tested, was homogeneous.

d. The distribution of the groups was normal.

e. The minimum number of group size was 50.

Assumptions a, b, c and e were met by E-I gender index, E-I caste index, and E-I LPG adoption status index in all the 4 groups of network data (LPG women, non-LPG women, LPG men, non-LPG men). Values of Shapiro-Wilk's test, skewness, and kurtosis were analyzed to examine the assumption of normality (appendix 5, Table 22). Measures which passed all the diagnostic tests were subjected to parametric Welch's t-test. Non-parametric Mann Whitney U test to compare medians was conducted for measures, which did not meet the normality assumption.

Bivariate analyses of compositional characteristics between LPG women and non-LPG women

E-I gender index

Welch's independent sample t-test was conducted to examine if there was a significant difference in mean values of the E-I gender index of ego networks of LPG women and of non-LPG women. There was a statistically significant difference in the mean values of the E-I gender index of ego networks of LPG women and that of non-LPG women ($t=-2.00$, $p=0.04$). The mean value of the E-I gender index of the ego networks of LPG women was -0.35 (SD=0.51). The mean value of the E-I gender index of the ego networks of non-LPG women was -0.19 (SD=0.52). Compared to personal networks of non-LPG women, personal networks of LPG women were more homophilic in nature (-0.35 is closer to the value of -1 than -0.19).

Results showed that LPG women were surrounded by higher proportion of women as alters than the proportion of men as alters in their personal networks. Non-LPG women were also surrounded by more women than men in their networks. However, the proportion of women as alters in non-LPG women networks significantly dropped when compared to that of proportion of women as alters in LPG women networks. This resulted in lower homophily in non-LPG women

networks compared to that of LPG women networks. For a more visual conception, Figure 14 depicts an actual ego network diagram from the data for LPG women and for non-LPG women exhibiting comparative gender based homophily between LPG women respondents and non-LPG women respondents.

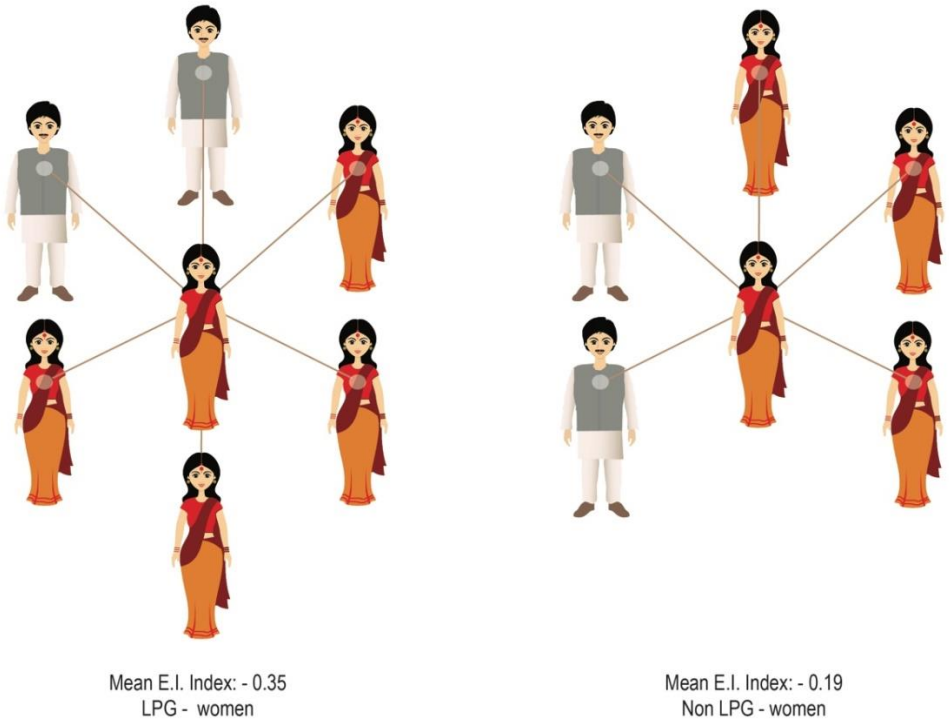


Figure 14: Mean E-I gender index for LPG women respondents and non-LPG women respondents

E-I caste index

Mann Whitney U test was conducted to examine if there was a significant difference in median values of the E-I caste index of ego networks of LPG women and of non-LPG women. There was no significant difference in the median value of the E-I caste index between the ego networks of LPG women and that of non-LPG women ($w=3312$, $p=0.81$). The median value of the E-I caste index of the ego networks of LPG women was -1 (IQR=0). The median value of the E-I caste index of the ego networks of non-LPG women was also -1(IQR=0). There was little distinction in caste representation as alters in personal networks of LPG women and of non-LPG women. No

significant difference in E-I caste index implied that alters had no relatively higher representation from the same caste as that of their egos in the personal network. Both network groups (LPG women and non-LPG women) had alters from almost all caste groups.

E-I LPG adoption status index

Welch's t-test was conducted to examine if there was a significant difference in mean values of the E-I LPG adoption status of ego networks of LPG women and that of non-LPG women. In other words, the t-test was conducted to explore if LPG women were surrounded with higher proportion of alters, who also had taken up LPG, when compared to the LPG adoption status of alters of non-LPG women networks. There was a strong statistically significant difference in the mean value of the E-I LPG adoption status index between the ego networks of LPG women and that of non-LPG women ($t=-7.29$, $p<0.001$). The mean value of the E-I LPG adoption status index of the ego networks of LPG women was -0.55 (SD=0.46). The mean value of the E-I gender index of the ego networks of non-LPG women was +0.03 (SD=0.56). Compared to personal networks of non-LPG women, personal networks of LPG women were strongly homophilic in nature (-0.55 is closer to the value of -1 than +0.03).

LPG women were surrounded by significantly higher proportion of alters who had adopted LPG than the proportion of alters who had not adopted LPG. Non-LPG women were also surrounded by few alters who had adopted LPG. However, the t-test showed that this proportion significantly dropped when compared to that of alters in LPG women networks. Figure 15 depicts an actual ego network diagram from the data for LPG women and for non-LPG women exhibiting comparative LPG adoption status of alters. The figure shows that LPG women networks were composed of proportion of alters who had taken up LPG, which far outstrips the proportion of alters who had taken up LPG in non-LPG women networks.

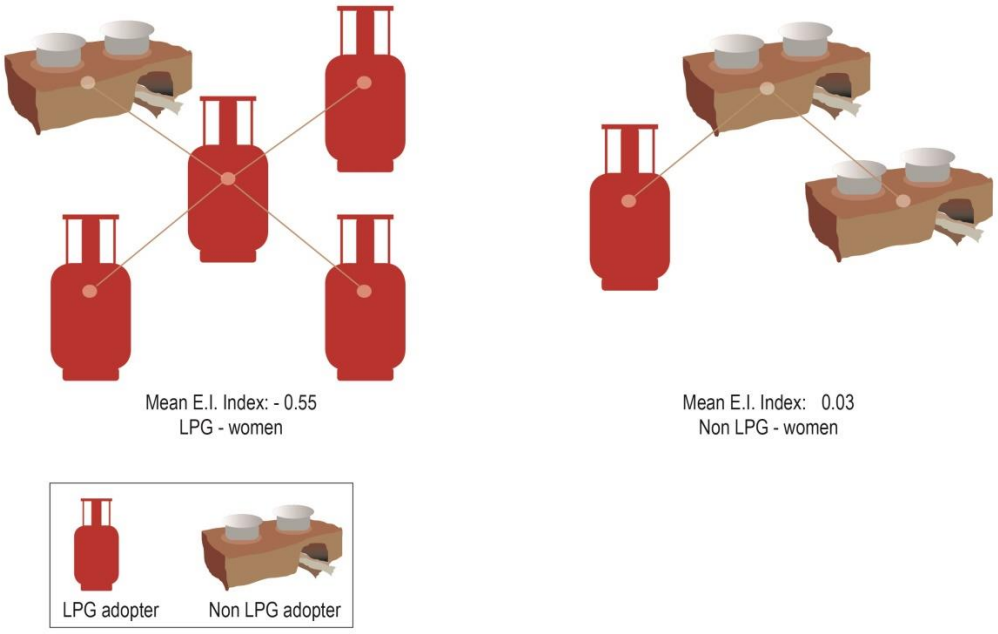


Figure 15: Mean E-I LPG adoption status index for LPG women respondents and non-LPG women respondents

Bivariate analyses of compositional characteristics between LPG men and non-LPG men

E-I gender index

Welch's t-test was conducted to examine a significant difference in mean values of the E-I gender index of ego networks of LPG men and of non-LPG men. Data showed that there was a statistically significant difference in the mean values of the E-I gender index of ego networks of LPG men and that of non-LPG men ($t=-3.72$, $p<0.001$). The mean value of the E-I gender index of the ego networks of LPG men was -0.65 (SD=0.42). The mean value of the E-I gender index of the ego networks of non-LPG men was -0.40 (SD=0.47). Results showed that compared to personal networks of non-LPG men, personal networks of LPG men were more homophilic in nature (-0.65 is closer to the value of -1 than -0.40).

Personal networks of LPG men were composed of relatively higher proportion of men as alters than the proportion of women as alters. Personal networks of non-LPG men were also

composed of more number of men as alters than the number of women as alters. However, the proportion of men as alters significantly dropped in personal networks of non-LPG men when compared to that of the personal networks of LPG men. Figure 16 depicts an actual ego network diagram from the data for LPG men and for non-LPG men exhibiting comparative gender based homophily.

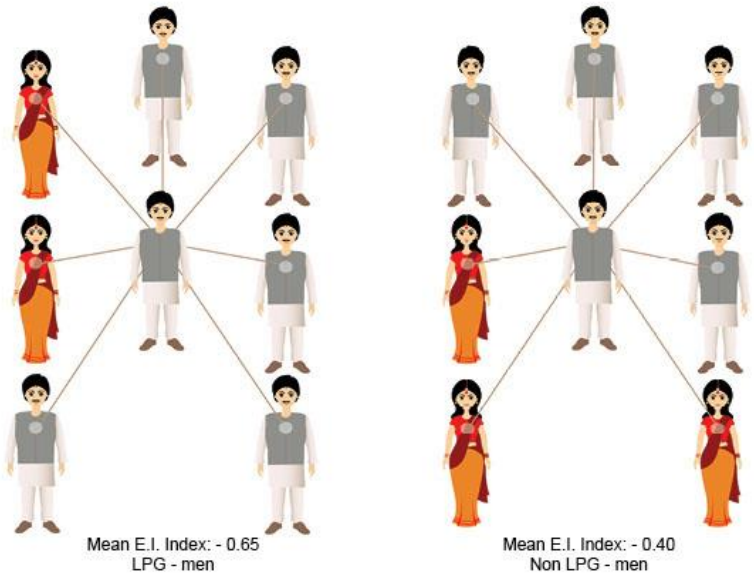


Figure 16: Mean E-I gender index for LPG men respondents and non-LPG men respondents

E-I caste index

Mann Whitney U test was conducted to examine if there was a significant difference in median values of the E-I caste index of ego networks of LPG men and non-LPG men. No significant difference was found in the median value of the E-I caste index between ego networks of LPG men and that of non-LPG men ($w=3582$, $p=0.39$). The median value of the E-I caste index of the ego networks of LPG men was -1 (IQR=0.49). The median value of the E-I caste index of the ego networks of non-LPG men was -1 (IQR=0.32). As demonstrated by the results, there was no significant distinction in caste representation as alters for personal networks of LPG men and non-LPG men. In other words, alters had no relatively higher representation from the same caste as that

of their corresponding egos in the network. Both network groups (LPG men and non-LPG men) had alters from all caste groups.

E-I LPG adoption status index

Welch's two sample t-test was conducted to examine if there was a significant difference in mean values of the E-I LPG adoption status of ego networks of LPG men and of non-LPG men. In other words, the t-test was conducted to explore if LPG men's personal networks were composed of higher proportion of alters who had taken up LPG compared to the proportion of alters who had taken up LPG in non-LPG men's personal networks. There was a strong statistically significant difference in the mean value of the E-I LPG adoption status index between the ego networks of LPG men and that of non-LPG men ($t=-5.52$, $p<0.001$). The mean value of the E-I LPG adoption status index of the ego networks of LPG men was -0.58 (SD=0.47). The mean value of the E-I LPG adoption status index of the ego networks of non-LPG men was -0.15 (SD=0.50). Compared to personal networks of non-LPG men, personal networks of LPG men were strongly homophilic in nature (-0.58 is closer to the value of -1 than -0.15).

LPG men's networks were composed of higher proportion of alters, who had taken up LPG than the proportion of alters, who had taken up LPG in non-LPG men's networks. Figure 17 depicts an actual ego network diagram from the data for LPG men and for non-LPG men exhibiting comparative LPG adoption status of alters of LPG men and of non-LPG men. The figure shows that LPG men's networks were composed of higher proportion of alters who had taken up LPG, which far outstrips the proportion of alters who had taken up LPG in non-LPG men's personal networks.

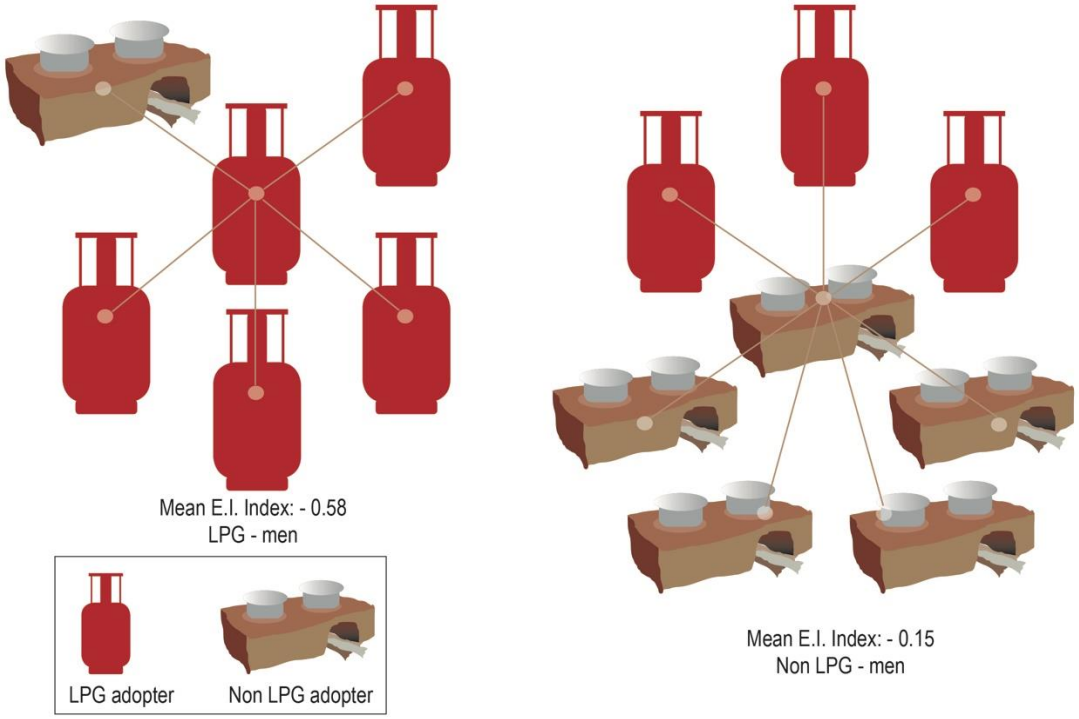


Figure 17: E-I LPG adoption status index for LPG men respondents and non-LPG men respondents

5.3 Summary of findings for aim 1

Aim 1: To understand how rural LPG adopters vary from other rural households on factors of affordability, accessibility, and awareness of LPG *(aim 1: adoption)*

Following hypotheses categorized as affordability, accessibility, and awareness related characteristics were tested for aim 1. Pattern of association between the predictors and the outcome variable was mostly consistent in the bivariate relationship and in respective binomial regression models.

Demographic measure

H1a: General caste households are more likely to adopt LPG than households that belong to other caste group households (OBCs, and SC/STs) and religious minorities.

This hypothesis was supported by all the regression models [model 1 (demographic measures), model 2 (affordability), model 3 (accessibility), model 4 (awareness), and model 5 (3As)]. From model 1, controlling for all other demographic predictors, SC/ST caste respondents (compared to General caste respondents) were 89% less likely to adopt LPG (OR=0.11, CI: 0.05-0.20). OBC castes and other religious minorities were not significantly associated in model 1. From model 2, SC/ST caste respondents were 87% less likely to adopt LPG compared to the General caste respondents (OR=0.13, CI: 0.06-0.27). OBCs and religious minorities had no significant association in this model. From model 3, controlling for all other variables in the model, the SC/STs were 99.92% less likely to adopt LPG than the General caste groups (OR=0.08, CI: 0.04-0.18). OBCs and religious minorities had no significant association in this model. From model 4, controlling for all other variables in the model, the SC/ST caste groups were 91% less likely to adopt LPG than the General caste groups (OR=0.09, CI: 0.04-0.18). OBCs had no significant association in this model. From model 5, controlling for all other variables in the model, the SC/ST caste groups were 89% less likely to adopt LPG than the General caste groups (OR=0.11, CI: 0.04-0.20). OBC caste groups and other religious minorities had no significant association with LPG adoption. To summarize from all the 5 models, SC/ST caste households were less likely to adopt LPG than the General caste households.

Affordability related measures

H1b: Households whose respondents (women) have a higher income are more likely to adopt LPG compared to households with respondents with lower income.

Both the binomial regressions model 2 (affordability) and model 5 (3As) supported this hypothesis. From model 2, it was observed that with every unit increase in income of the respondents, the odds of adopting LPG increased by only 0.02%, after controlling for the demographic predictors (OR=1.0002, CI: 1.00009-1.0004). From model 5, it was observed that with

every unit increase in income of the respondents, the odds of adopting LPG increased by 0.06%, after controlling for accessibility, awareness, and demographic predictors (OR=1.0006, CI: 1.0003-1.0009). To summarize from these two models, higher income of the respondents increased the likelihood of LPG adoption.

H1c: Households whose respondents are members of self-help groups (SHG) are more likely to adopt LPG compared to the households whose respondents are not members of any self-help group.

Model 2 supported this hypothesis. From model 2, while controlling for the demographic predictors, the respondents were members of an SHG were 81% more likely to adopt LPG than the respondents who held no SHG memberships (OR=1.81, CI: 1.16-2.86). However model 5, which controlled for demographic, accessibility, and awareness related measures, did not support this hypothesis. Thus, while model 2 showed that affiliation of respondents with SHGs increase the likelihood of LPG adoption, model 5 did not support this claim.

H1d: Households with higher gross income are more likely to adopt LPG than the households with lower gross income.

Both model 2 (affordability) and model 5 (3As) supported this hypothesis. From model 2, with every unit increase in total income of the households, the odds of adopting LPG increased by 0.03%, after controlling for the demographic predictors (OR=1.0003, CI: 1.0001-1.0004). From model 5, similarly, with every unit increase in total income of the households, the odds of adopting LPG increased by only 0.02%, while controlling for accessibility, awareness, and demographic predictors (OR=1.0002, CI: 1.00003-1.0004). To summarize from both the models, households with higher income were more likely to adopt LPG.

H1e: Households with higher land holdings are more likely to adopt LPG than the households with lower land holdings.

Neither model 2 nor model 5 supported this hypothesis.

H1f: Households with higher agricultural debt are more likely to adopt LPG than the households with lower agricultural debt.

Both model 2 (affordability) and model 5 (3As) supported this hypothesis. From model 2, while controlling for the demographic predictors, the households with agricultural debt (relative to households with no debt) were 0.001% more likely to adopt an LPG (OR=1.00001, CI: 1.00e+00 – 1.00e+00). From model 5, controlling for the accessibility, awareness, and demographic predictors, the households with agricultural debt (relative to households with no debt) were 0.002% more likely to adopt an LPG (OR=1.00002, CI: 1.00e+00 – 1.00e+00). Thus from both the models, it could be summarized that households with higher agricultural debt had higher likelihood to adopt LPG.

Accessibility related measures

H1g: Increase in the distance to tarmac roads from the household reduces the likelihood of that household to adopt LPG.

Both model 3 (accessibility) and model 5 (3As) supported this hypothesis. From model 3, controlling for all the demographic predictors, with every unit increase in the distance of the nearest tarmac road from the respondents' household, there was a 27% less likelihood to adopt LPG by the respondents (OR=0.73, CI: 0.54-0.89). Similarly, from model 5, controlling for the affordability, awareness, and demographic predictors, with every unit increase in the distance of the nearest tarmac road from the respondents' household, there was a 26% less likelihood to adopt LPG by the respondents (OR=0.74, CI: 0.57-0.96). Thus, increase in the distance to the nearest tarmac roads decreased the likelihood for the households to adopt LPG.

H1h: Increase in the distance to LPG distribution centers from the household reduces the likelihood of that household to adopt LPG.

Neither model 3 (accessibility) nor model 5 (3As) supported this hypothesis.

H1i: There is a lower likelihood to adopt LPG in households where the respondents prefer smaller LPG cylinders over the larger cylinders in circulation.

Neither model 3 (accessibility) nor model 5 (3As) supported this hypothesis.

H1j: There is a lower likelihood of household adoption of LPG when the respondents feel that biomass is easily available.

Both model 3 and model 5 supported this hypothesis. From model 3, controlling for all the demographic predictors, respondents who felt that free availability biomass deter clean stove adoption were 99.98% less likely to adopt LPG (OR=0.02, CI: 0.003-0.007). From model 5, controlling for the affordability, awareness, and demographic predictors, respondents who felt that free availability biomass deter clean stove adoption were 99.99% less likely to adopt LPG (OR=0.01, CI: 7e-4 - 3.3e-02). Thus from both the models, it could be summarized that availability of free biomass deterred LPG adoption.

H1k: Increase in the distance to the source of biomass from the households increases the likelihood of those households to adopt LPG.

Both model 3 and model 5 supported this hypothesis. From model 3, controlling for all the demographic predictors, with every unit increase in the distance of the biomass source from the respondents' household, there was an 18% more likelihood to adopt LPG by the respondents (OR=1.18, CI: 1.01-1.39). Similarly, from model 5, controlling for the affordability, awareness, and demographic predictors, with every unit increase in the distance of the biomass source from the respondents' household, there was a 20% more likelihood to adopt LPG by the respondents (OR=1.20, CI: 1.00-1.44). Thus, to summarize from both the models, increase in the distance to nearby biomass source drove LPG adoption.

H1l: There is a higher likelihood of those households to adopt LPG, whose respondents (women) are involved in decision making to purchase new stoves.

Neither model 3 (accessibility) nor model 5 (3As) supported this hypothesis.

Awareness related measures

H1m: There is a lower likelihood for households to adopt LPG, when respondents feel that LPG cylinders are unsafe.

Both model 4 and model 5 supported this hypothesis. From model 3, those respondents who perceived the possibility of LPG explosion as a contributing factor to base their decisions about LPG ownership were 93% less likely to adopt LPG, compared to those respondents who did not perceive this possibility as contributing factor towards making adoption choices (OR=0.07, CI: 0.02-0.17). Similarly, from model 5, those respondents who perceived the possibility of LPG explosion as a contributing factor influencing decisions on LPG ownership were 89% less likely to adopt LPG, compared to those respondents who did not perceive this possibility as contributing factor towards making adoption choices (OR=0.11, CI: 0.03-0.3). Thus, from both the models it could be summarized that a persistent "belief" that LPG cylinder could explode causing household damage deterred households to adopt LPG.

H1n: There is a lower likelihood of households to adopt LPG when respondents feel that LPG is incompatible with traditional cooking practices.

Model 4 supported this hypothesis. From model 4, the respondents who believed that use of LPG is against their traditional cooking culture were 91% less likely to adopt LPG, than the respondents who did not believe that use of LPG is against their traditional culture (OR=0.09, CI: 0.004-0.72). Model 5 did not support this hypothesis. Thus, to summarize, while model 4 showed that perception of LPG against traditional cooking culture reduced their adoption; model 5 did not support this claim.

H1o: Respondents are more likely to adopt LPG, when it enhances the social status of their households in their respective communities.

Model 4 supported this hypothesis. Respondents who felt that LPG enhances their social status were 7.02 times more likely to adopt LPG than the respondents who did not feel that LPG would enhance their social status (OR=7.02, CI: 1.14-60.84). However, model 5 did not support this hypothesis. In other words, while model 4 showed that perception of LPG as "enhancer" of social status increased the likelihood of LPG adoption, model 5 did not support this claim.

H1p: Those households where respondents have attended at least one in-person awareness campaign on LPG adoption are more likely to adopt LPG than households where respondents have not attended any in-person awareness campaign on LPG adoption.

Both model 4 and model 5 supported this hypothesis. From model 4, controlling for the demographic predictors, those respondents who attended at least one campaign on LPG adoption and use were 6.23 times more likely to adopt LPG than the respondents who did not attend any campaign on LPG adoption and use (OR=6.23, CI: 2.49-17.75). Similarly, from model 5, while controlling for the demographic, affordability, and accessibility related measures, respondents who attended at least one campaign on LPG adoption and use were 17.51 times more likely to adopt LPG than the respondents who did not attend any campaign on LPG adoption and use (OR=17.51, CI: 4.09-122.25). To summarize, both models strongly supported the claim that attending campaigns drove LPG adoption.

5.4 Summary of findings for aim 2

Aim 2: To evaluate the relative influence of gender based personal networks on LPG adoption in rural households *(aim 2: personal network analysis)*

Following hypotheses categorized as structural characteristics and compositional characteristics were tested for this aim in this study.

Structural characteristics

H2a: Personal networks of women in LPG adopter households have higher structural holes than that of women in non-LPG adopter households.

H2b: Personal networks of men in LPG adopter households have higher structural holes than that of men in non-LPG adopter households.

Hypothesis H2a was not supported by the data. Hypothesis H2b was supported by the data. Higher structural holes in an ego network are characterized with higher effective size. The likelihood to receive novel information is higher with higher number of structural holes. There was a significant difference in the mean value of effective size between personal networks of LPG men and of non-LPG men. The mean value of effective size was statistically significantly higher in personal networks of LPG men than that of non-LPG men ($t=2.02$, $p=0.04$).

Compositional characteristics

H2c: Personal networks of women in LPG adopter households have higher gender based homophily than that of women in non-LPG adopter households.

H2d: Personal networks of men in LPG adopter households have higher gender based homophily than that of men in non-LPG adopter households.

Both the hypotheses H2c and H2d were supported by the study. Krackhardt & Stern's E-I index was calculated to examine the gender based homophily. The E-I index ranges between -1 to +1. The index closer to -1 shows relatively higher homophily (lower heterophily) in personal networks. The index closer to +1 shows relatively higher heterophily (lower homophily).

The E-I index showed that personal networks of LPG women were composed of significantly higher proportion of women than that of the personal networks of non-LPG women. This indicated significantly higher gender based homophily in personal networks of LPG women compared to that of non-LPG women ($t=-2.00$, $p=0.04$). LPG women surround themselves with more women than

men as their alters in their personal networks compared to that of the personal networks of non-LPG women.

The E-I index showed that personal networks of LPG men were composed of significantly higher proportion of men than that of personal networks of non-LPG men. This again indicated that there was a significantly higher gender based homophily in personal networks of LPG men than that of non-LPG men ($t=-3.72$, $p<0.001$). LPG men surround themselves with more men than women as their alters in their personal networks compared to that of the personal networks of non-LPG men.

H2e: Personal networks of women in LPG adopter households have higher caste based homophily than that of women in non-LPG adopter households.

H2f: Personal networks of men in LPG adopter households have higher caste based homophily than that of men in non-LPG adopter households.

The study did not support the hypotheses H2e and H2f. Results showed that there was no significant difference in caste based homophily in personal networks of: 1) LPG women and non-LPG women; and also 2) LPG men and non-LPG men. Personal networks of the respondents were composed of representations from all caste groups, and there was no significant difference between LPG adopters and non-LPG adopters in terms of the caste of their alters. Disparities in any relatively dominant caste group as alters could not be found between LPG adopters and non-LPG adopters. Egos, irrespective of their own caste identities, had alter connection from all caste groups with no significant difference.

H2g: Personal networks of women in LPG adopter households have higher homophily in LPG adoption than that of women in non-LPG adopter households.

H2h: Personal networks of men in LPG adopter households have higher homophily in LPG adoption than that of men in non-LPG adopter households.

Both the hypotheses H2g and H2h were supported by the study. Krackhardt & Stern's E-I index was calculated to examine the homophily in terms of LPG adoption.

The E-I index showed that personal networks of LPG women were composed of significantly higher proportion of LPG adopters as alters than that of the personal networks of non-LPG women ($t=-7.29$, $p<0.001$). LPG women surround themselves with relatively more number of alters who also had taken up LPG than the number of alters who did not take up LPG. On the other hand, non-LPG women surround themselves with relatively more number of alters who did not take up LPG than the number of alters who did take up LPG.

The comparative pattern in women's networks repeated in men's personal networks too. The E-I index showed that personal networks of LPG men were composed of significantly higher proportion of LPG adopters as alters than that of the personal networks of non-LPG men ($t=-5.52$, $p<0.001$). There was a significantly higher homophily in terms of LPG adoption status in personal networks of LPG men than that of non-LPG men. LPG men surround themselves with relatively more number of alters who also had taken up LPG than the number of alters who did not take up LPG. Non-LPG men surround themselves with relatively more number of alters who did not take up LPG than the number of alters who did take up LPG.

5.5 Concluding remarks

This chapter presented the results of the two aims of the study. Aim 1 demonstrated that there was a concurrent impact of affordability, accessibility, and awareness on LPG adoption. Through binomial logistic regression models, results of aim 1 showed different measures within each of the concepts of affordability, accessibility, and awareness and their relative contribution in determining LPG adoption. A missing piece in aim 1 was to explore if personal gender based networks within the concept of awareness might also determine LPG adoption. Aim 2 complemented aim 1 by studying this missing piece. Aim 2 demonstrated how social capital differs in different gender based

networks. Results of aim 2 complimented results of aim 1, and extended the argument that personal networks might also determine the likelihood of who would take up LPG, and who would not in these communities. The next chapter analyzes these results in detail.

VI. Discussion

6.0 Organization of this chapter

This chapter is organized as follows. Section 6.1 and section 6.2 cover detailed analyses over the findings of aim 1 (adoption) and of aim 2 (personal network analyses) respectively. Section 6.3 provides an overall discussion of the findings from both these aims, and how they align with the RE-AIM framework. Section 6.4 discusses the limitations of the study. The study has a few significant implications for policy and practice in the clean cooking sector. Also, this study provides scope and agenda for continued research. Section 6.5 elucidates implications for policy and practice, while section 6.6 discusses implications for future research. Section 6.7 concludes.

6.1 Analysis of aim 1

According to the 2011 census, only 28.5% of households in India considered LPG as their primary cooking fuel (Tripathi et al., 2015). This fact seems more deplorable when the data is bifurcated between rural and urban households. Only 11% of rural households stated that LPG was their primary cooking fuel compared to 65% in urban households (Tripathi et al., 2015). As part of a concerted push toward a low carbon economy, and to address social, environmental, and public health challenges of HAP, the last few years have witnessed a renewed attention on providing cleaner cooking solutions -especially LPG- to rural poor in India (Kumar, Kaushalendra Rao, & Reddy, 2016). National and state level government programs such as "Give it up campaign," *"Pradhan Mantri Ujjwala Yojana (PMUY)"*, *"Rajiv Gandhi Gramin LPG Vitaran Yojana (RGGLVY)"*, or *"Deepam"* exhibit the current focus of the Indian government on addressing challenges associated to HAP. R. E. Glasgow et al. (1999) and Neta et al. (2015) emphasize exploring the determinants of adoption and maintenance of such welfare programs through the lens of the RE-AIM framework. The evaluation of welfare programs through the RE-AIM framework provides insights into ways to reduce implementation leakage, and to expedite program integration in routine practice of users.

This aim tested the conceptual model (Figure 10) to investigate if there was a concurrent impact of affordability, accessibility, and awareness (3As) on adoption (initial uptake) of LPG. The aim was explored by collecting data from 255 LPG adopter households and 255 non-LPG adopter households in BPL communities of the state of Andhra Pradesh in rural India. The analyses involved developing 5 binomial logistic regression models. The findings were in part consistent with previous studies on clean cooking adoption. They further expanded the current understanding on the determinants of LPG adoption by rural poor.

Caste and LPG adoption

Findings from models 1-5 showed that there were disparities in adoption of LPG between SC/ST households and the General caste households. This is consistent with findings from earlier clean cooking adoption studies (Jain et al., 2014; Lewis et al., 2015; J. J. Lewis & S. K. Pattanayak, 2012; Yadama, 2013b). Majority of the study sample households were beneficiaries of national or state level LPG welfare schemes. These government led LPG programs base their implementation criteria on household income with no explicit motive to benefit a particular caste group. However, the findings suggest that LPG adoption status at least partly could be explained by caste of the respective households.

Higher income and greater accessibility to resources are still skewed toward General caste groups relative to other caste groups especially the SC/STs in rural communities. Models 2-5 controlled for the measures pertaining to affordability, accessibility, and awareness (3As). Despite this, the disparity in LPG adoption between SC/ST caste respondents and General caste respondents remained fairly constant and significant in these models. This means that variance in LPG adoption could in part be explained by the inherent social status of these households sanctioned by their corresponding caste groups, which was not explained by the variables pertaining to the 3As. Socially sanctioned privileges of General caste households perpetuate disparities and

confer them with higher honor in communities. Social inequalities in such communities exist, sometimes despite little inequality in their relative economic status (Ali, 2007). To maintain this status quo of structural superiority, General caste households harness more economic and social capital, take relatively higher risk, and show higher propensity to adopt a social or technological innovation such as cleaner cooking systems. Adoption of LPG could be seen as a "class differentiator" (J. J. Lewis & S. K. Pattanayak, 2012). This behavior gains momentum especially when higher caste households through institutional hegemony could no more "systemically deprive" SC/STs to better alternatives such as LPG. This leaves the dominant caste groups to expedite adoption of newer technologies to maintain their "elitist" status in such communities relative to marginalized caste groups such as SC/STs.

Communities in the study sites have a dominant presence of OBC caste households. OBC households in these *mandals* (blocks) have a relatively stronger representation in Gram Panchayats (local self-governments) than that of the SC/ST households. Representation of OBCs in local self-governments has reduced social inequality at least between the OBCs and the General caste groups in these communities. However, the inequality persists between the OBCs and the SC/ST households. This explains no significant difference in LPG adoption status between General caste households and OBC caste households in these communities.

Affordability and LPG adoption

There were five predictors related to affordability, which were tested in model 2 (affordability) while controlling for all demographic predictors, and in model 5 (3As) while controlling for demographic, accessibility, and awareness related predictors. These predictors were: 1) income of the household; 2) income of the respondent; 3) membership of SHGs; 4) land ownership of the household; 5) agricultural debt of the household.

The findings on association between income and LPG adoption were consistent with the existing studies on clean cooking adoption (El Tayeb Muneer & Mukhtar Mohamed, 2003; Geremew, Gedefaw, Dagnew, & Jara, 2014; Kumar & Mehta, 2016; J. J. Lewis & S. K. Pattanayak, 2012; Pine et al., 2011). The energy poor households in these rural communities experience sporadic livelihood shocks, which impact both their income and its regularity (Yadama, 2013b). Livelihood risks constrain households from substituting traditional cooking with modern cooking practices especially when there is limited economic incentive. Adoption of relatively expensive cooking systems such as LPG necessitates households to have relatively higher income.

Income from the respondents (women) brings economic autonomy to women. This serves two purposes: 1) contributes to the overall gross income of the household; 2) improves the bargaining capacity of women on their personal well-being in the household (Cecelski, 2000; El Tayeb Muneer & Mukhtar Mohamed, 2003). Thus, findings showed that controlling for other attributes of accessibility and adequate awareness; both higher gross income of households and higher income of respondents (women) increased the propensity of the households to shift to LPG. It must be noted that at the bivariate level both higher income of the respondents ($w=198390$, $p<0.001$) and higher income of the households ($w=256530$, $p<0.001$) had a strong association with LPG adoption. The median value of the income of the respondents associated with adoption of an LPG was INR 1100 per month. On the other hand if the median income of the respondents was INR 750 per month, it was associated with non-adoption of LPG. Similarly, the median value of the income of the households associated with adoption of an LPG was INR 3000 per month. On the other hand if the median income of the households was INR 2000 per month, it was associated with non-adoption of LPG. When these predictors were used in multivariate regression, although they were positively associated with LPG adoption, the strength of the association of both income of the respondents (OR=1.0002, CI: 1.00009-1.0004) and income of the households (OR=1.0003, CI:

1.0001-1.0004) was weak. This shows that variance in adoption of LPG was also significantly explained by other predictors unrelated to income.

When the predictor "exposure to campaigns" was added to model 5, the predictive capacity of "membership of SHGs" dropped in model 5 compared to that of model 2, when the predictor "exposure to campaigns" was not controlled for. Adoption of LPG in these study habitations have been driven by either national or state level programs targeted for BPL households. A prime function of the SHGs is to serve as an instrument of awareness generation among the women affiliates about factors which might enhance their well-being including clean cooking stoves (Rajakutty & Kojima, 2002). Therefore, when the predictor "exposure to campaigns" was introduced in model 5, relatively higher variance in LPG adoption was explained by this predictor. This accounted for the drop in the significant association of the membership of SHGs with LPG adoption in model 5.

It was interesting that land holdings of the households could not significantly predict LPG adoption. The findings suggest that even if the households had relatively higher land holdings, still they were at a higher risk of not adopting LPG. Land ownership of households did not appear to significantly differentiate the LPG adopters from the non-adopters.

With growing economic liberalization in India, there has been a rise in the number of financial institutions providing agricultural credit to rural households. Households with higher risk taking capacity are associated with higher demand for agricultural credit. These households take greater risks and convert them into an opportunity with greater benefits. The capacity to take risks and justifying their need are qualities associated with higher receptivity to innovation. These households are more likely to be open to adopting newer technological innovation in their households for their well-being. Households with higher agricultural debt are symptomatic of relatively higher risk taking capacity of those households. This explains significant association in both model 2 and model 5 of

LPG adoption with higher agricultural debt in households. It must be noted that at the bivariate level higher agricultural debt was strongly associated with LPG adoption ($w=81090$, $p<0.001$). When the predictor agricultural debt was used in multivariate regression, although it was positively associated with LPG adoption, the strength of the association was weak (OR=1.00002, CI: 1.00e+00 – 1.00e+00).

There was a positive but weak association of: 1) higher income of respondents; 2) higher income of the households; and 3) higher agricultural debt, with LPG adoption in multivariate regression models, when controlled for accessibility and awareness related predictors. Each of these predictors had a strong association with LPG adoption at the bivariate level. It could be conceived that while affordability related measures determine LPG adoption, the variance in LPG adoption is also significantly explained by other predictors pertaining to accessibility and awareness. These predictors are analyzed subsequently.

Accessibility and LPG adoption

Accessibility to LPG cylinders among households is made possible through two ways in India: 1) self-delivery by LPG distributors; 2) procurement of cylinders by consumers. These heavy 29.6 Kg cylinders require use of vehicles to deliver them to respective households irrespective of the mode of the availability. At the bivariate level, LPG adoption was significantly associated with shorter distance to the LPG distribution centers. The boxplot in Figure 18 clearly shows the disparity in LPG adoption by distance to the nearest LPG distribution center. The mean value of the distance to the nearest LPG distribution center for LPG adopter households was 9.07 Kms while the mean value of the distance to the nearest LPG distribution center for non-LPG adopter households was 8.16 Kms.

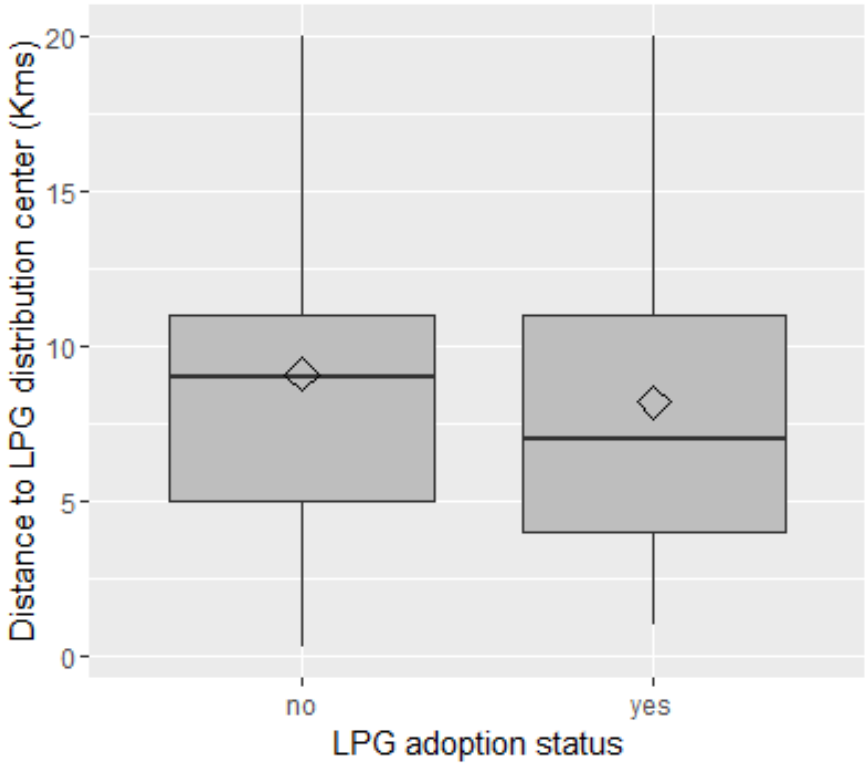


Figure 18: LPG adoption disparity by distance to the nearest LPG distribution center from the household

Proximity to tarmac roads also ensures easier availability of vehicles for transportation of LPG cylinders to rural poor. Rate of LPG adoption in rural interiors remains stymied due to infrastructural barriers such as lack of tarmac roads (Jain et al., 2014). The findings supported this claim. Figure 19 shows a boxplot showing a significant difference in distance of the households from the nearest tarmac roads for the two household groups of LPG adopters and non-LPG adopters. The households, which are in the interiors and farther away from the nearest tarmac roads, are clearly less likely to adopt LPG.

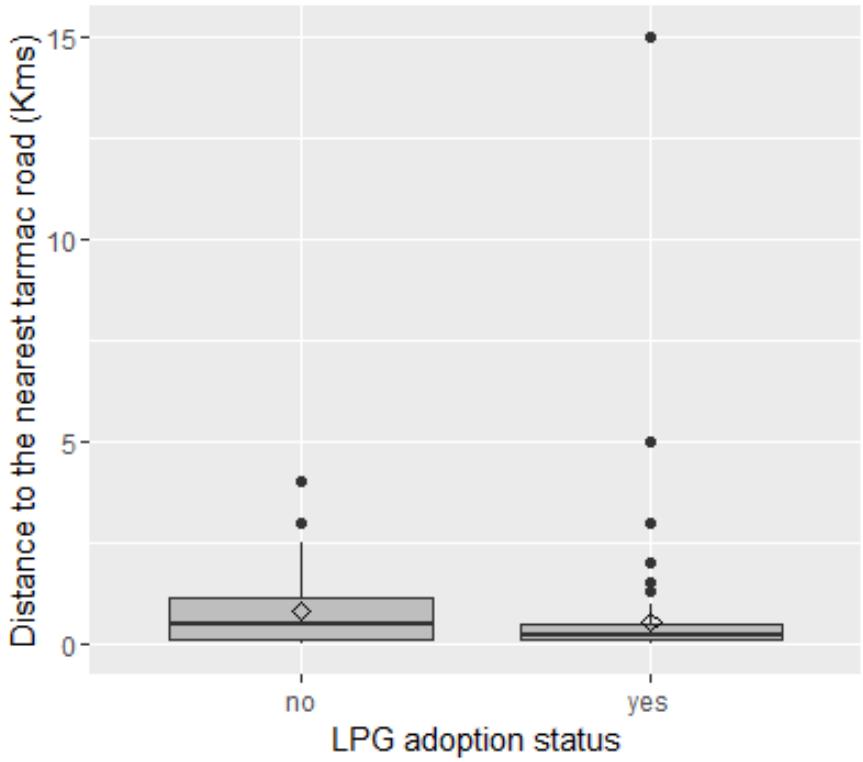


Figure 19: LPG adoption disparity by distance to the tarmac road from the household

It must be noted that in the regression models (model 3 and model 5); both the predictors preference to have smaller LPG cylinders and the distance to the nearest LPG distribution center were not significantly associated with adoption of LPG. However, in both the models shorter distance to the nearest tarmac road significantly predicted LPG adoption. The findings suggest that irrespective of the size of the LPG cylinders or the distance to the LPG distribution center from the households, if there is a better connectivity due to proximity to tarmac roads, likelihood to adopt LPG is relatively higher.

The findings from model 3 and model 5 supported Yadama et al. (2012) that free availability of biomass deterred households to adopt cleaner cooking replacements such as LPG stoves. LPG use provides a control over desired level of cooking power. This ensures considerable time saved due to faster cooking. The responsibility of collecting biomass in rural households falls primarily on women. Time used in collecting biomass could be utilized in alternative economic engagement,

which could lead to overall improved well-being of the household (Cecelski, 2000). Abandoning use of biomass could positively impact women's health and safety. However, women in rural households tend to prioritize collection of biomass over their health or economic engagement for a variety of reasons: 1) lack of adequate awareness on public health implications of biomass use; 2) traditional practices prevalent in communities dictating women to shoulder the drudgery of collecting biomass; 3) pursuit to save money on fuel by using free biomass available to these households; and 4) lack of potential economic opportunities for women in such communities. Even in cases where opportunities are available, rural households tend to undervalue the loss of opportunity cost of women's labor when there is an easy and free access to biomass. There is limited awareness in communities to equate the time gained by adopting LPG with potential economic engagement.

Figure 20 shows the difference in the mean distance of the LPG adopter and non-adopter households from the nearest source of the biomass. Increase in the distance to the source of biomass decreased accessibility to biomass. Consequently, propensity to shift to LPG increased. While the exact value of the distance to the biomass source that triggers adoption of LPG might be subjective, it could still be clearly conceived with the findings that greater availability of biomass clearly deters rural households to adopt LPG. Thus, the study showed that propensity to switch to LPG was higher, when there was reduced access to free biomass.

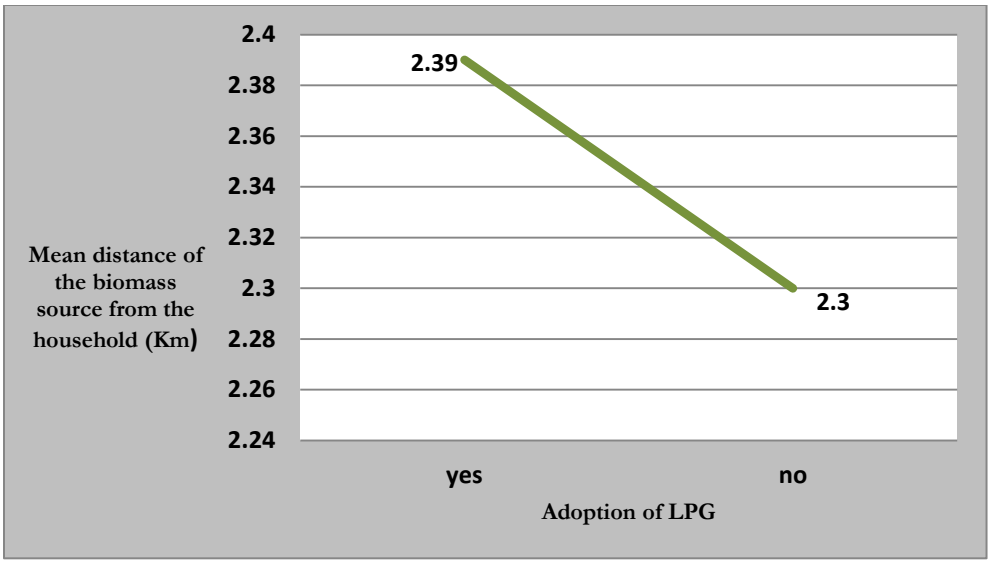


Figure 20: LPG adoption disparity by distance to the biomass source from the household

Awareness and LPG adoption

Numerous studies focusing on energy poverty in rural India show that cases exist where irrespective of adequate affordability and accessibility to LPG, adoption has been low due to lack of adequate awareness on LPG availability and benefits (Lewis & Pattanayak, 2012). Conceptions exist that potential gas leak is hazardous to health, and although infrequent but LPG explosions are fatal (Jain et al., 2014). Evidence exist where dominant caste groups imbue belief among vulnerable caste groups about hazardous consequences of adopting and using LPG (Wang, 2014). This is driven by the urge of dominant caste households to perpetuate systemic class difference between higher and lower caste groups. Persistent and dominant "belief" on detrimental consequences of LPG limits adoption in poor households (J. J. Lewis & S. K. Pattanayak, 2012; Wang, 2014). The findings from this study are in line with these studies. The non-adopters were not only concerned about the consequences of LPG explosion, but also explicated that this was one of the contributory factors which deterred them from adopting LPG.

When controlled only for demographic characteristics, model 4 (awareness) showed that respondents who believed that LPG was an indicator of social status in their habitations were more

likely to adopt LPG. In poor households, adoption of newer assets (especially newer technologies such as LPG) is perceived as an instrument of social superiority among peers. Although contextual, this behavior is prominent in communities, where households have a uniform level of asset ownership. The findings are in line with Rhodes et al. (2014), Sehjpal, Ramji, Soni, and Kumar (2014). The findings reveal that marginal addition to existing ownership of assets with an LPG cooking system by a household has a higher likelihood to improve the social status of the household.

Controlling for only demographic factors, model 4 showed that households who believed that LPG contradicted their traditional cooking practices were less likely to adopt LPG. Rural households consider traditional cooking as a critical part of their ancestral heritage (Rhodes et al., 2014). Although cooking might appear as a customary practice, it involves nuances varying across communities. Shift to LPG has been saddled with issues such as difference in flavor relative to traditional cooking or reduced flexibility in utensils to be used for cooking (Shonali Pachauri & Rao, 2013; Rhodes et al., 2014). In some communities there is a symbolic role of ash and ash products, which is absent with the use of LPG cooking systems (Rhodes et al., 2014). Households having a strong belief system fixated on their traditional cooking practices with limited room for potential adjustment show low propensity to shift to LPG.

It must be noted however, in model 5 (3As), where factors on affordability and accessibility of LPG were also controlled for, these two variables: 1) perception of LPG as an instrument of social status; and 2) LPG contradicting traditional practices, were not significant. It could be conceived that adequate affordability and better accessibility to LPG clearly reduce disparities between adopters and non-adopters in perceiving LPG as an instrument of social status or contradicting their traditional practices.

Rural households in India now have easy access to electronic and print media. Electronic media are prime sources of news. Awareness generation is a gradual process but requires a targeted

endeavor. Rural households fall short in having an adequate understanding of safety protocols in LPG use, which could address their hazard related perception of LPG. Even though media exposure is near pervasive in these rural communities, the findings showed that the households, which attended in-person awareness campaigns, were more likely to adopt LPG than the households, which did not attend any awareness campaign. This shows that in addition to media as effective communication channels, in-person awareness campaigns are crucial (Hollada et al., 2017; Jain et al., 2014; Lewis et al., 2015). Such campaigns provide practical demonstrations of effective LPG handling and engage in a bi-directional communication to address ignorance. They are central in expediting communities to adopt LPG. Targeted campaigns on safety awareness help these households to gain required confidence that adopting LPG is safe, abiding with safety protocols could minimize hazard, and could avert potential accidents.

This aim analyzed the relative contribution of multiple factors of awareness, which impacted LPG adoption. Everett M Rogers (2004), Acemoglu et al. (2011), and Delre, Jager, Bijmolt, and Janssen (2010) argue that adoption of social innovation is also determined by personal networks of individuals, an important channel of communication. Exploring how awareness might impact adoption of social innovation necessitates analyzing personal networks of individuals. Within the realm of the RE-AIM framework, R. E. Glasgow et al. (1999), R. E. Glasgow and Emmons (2007), and Simon, Bailis, Baumgartner, Hyman, and Laurent (2014) argue that structure and composition of personal networks determine adoption and sustained integration of innovation in routine practices of participants. Analyses of personal networks are thus crucial to further establish the relationship of dissemination of awareness as a determinant of adoption of social innovation such as cleaner cooking systems. This piece was missing in aim 1. Aim 2 complements aim 1 by adopting an ego network approach to analyze personal gender based networks of selected men and women

respondents from case (LPG adopters) and control (non-LPG adopters) households. Discussion on aim 2 is undertaken in the following section.

6.2 Analysis of aim 2

Acemoglu et al. (2011) and E. M. Rogers (1983) argue that structure and composition of personal networks determine awareness of potential adopters, which in turn impact the uptake of social innovation (such as LPG). Aim 2 of the study was in line with this argument. The objective was to explore if personal networks of women and men could provide cues on LPG adoption in these communities. In an attempt to answer to this objective, personal network data were collected from 100 LPG women respondents, 97 non-LPG women respondents, 82 LPG men respondents, and 82 non-LPG men respondents. The discussion here was driven by: 1) hypotheses on structural characteristics of personal networks, which discussed the influence of structural holes on adoption of LPG; and 2) hypotheses on compositional characteristics of personal networks, which discussed composition of caste, gender, and LPG adoption status of alters relative to their corresponding egos. Structural position of egos and composition of alters in personal networks impact decision making behavior of egos on innovation uptake (Brown & Ashman, 1996; Burt, 1980; Burt, 2009). This study is the first of its kind to explore the role of ego-centric networks on cleaner cooking adoption in rural poor communities.

Structural characteristics of personal networks

Previous research claims that structure of ego networks determine the level of social capital at the disposal of egos (Ahuja, 2000). Structural holes or the degree of disconnected alters provide an optimal strategy for egos to receive novel information (Burt, 2009). Structural holes can be measured by examining effective size of egos in their personal network. Effective size of an ego network is the degree to which an ego can obtain newer information and control benefits from non-redundant ties. Relatively higher effective size means higher structural holes in a network. Relatively higher

structural holes in their personal networks facilitate egos to be at the crossroads between alters, positions them to receive novel information. Relatively higher structural holes enhance the likelihood for the egos to adopt and integrate innovation in their routine practices comparatively more than the egos with relatively lower structural holes.

Findings in this study were in coherence with Ramirez et al. (2013), Ahuja (2000), and Miller and Mobarak (2015). These studies argued that structural positioning could help specific nodes in information-rich network to have a relatively higher propensity to adopt technological innovation. The results in this study showed that there was a significant difference in the effective size of ego networks between LPG men and non-LPG men. This means that structural holes in personal networks of men from LPG adopter households were significantly higher than that of the personal networks of men from non-LPG adopter households. Significant difference in effective size indicated that structural positioning of egos in their personal networks between case and control groups varied. There were relatively higher distinct connection gaps among alters of LPG men than that of non-LPG men. This facilitated the egos in personal networks of LPG men to serve as stronger information conduits between the unconnected alters in their networks. Likelihood of receiving novel information on technological innovation (such as LPG) was relatively higher in LPG men due to relative maximization of structural holes. LPG men (relative to non-LPG men) were at a structurally beneficial position: 1) to receive novel information on newer cooking technologies; 2) and to relatively expand their diversity of information with the help of their corresponding unconnected alters. Adoption of technological innovation such as LPG in close knitted rural communities have less to do with how many people (network size) an ego is connected with, and has more to do with how these people are structurally positioned relative to an ego (Burt, 2001).

The findings showed that there was no significant difference in the effective size of LPG women and of non-LPG women. Lack of significant variation in effective size indicated that LPG

women and non-LPG women have fairly equivalent degree of structural holes (Burt, 1980, 1984). No significant variation in structural holes reduced the likelihood of novel information to reach to women in both the groups (LPG adopters and non-LPG adopters). This is not uncommon in women's networks among proximal households in rural communities. Women's personal networks in rural settings tend to be more localized, closely knitted, and with a higher likelihood of interconnected alters (Ramirez et al., 2013). In other words, women's personal networks could be characterized as networks where *"everyone knows everyone else"*. This might be more effective for expeditious dissemination of information within the network. However, this reduces likelihood of newer information reaching to the egos. The findings were consistent with results from the study on diffusion of non-traditional cookstoves in Honduras by Ramirez et al. (2013).

Compositional characteristics of personal networks

Burt (2009) and Acemoglu et al. (2011) argue that disconnected alters are optimal structural pattern for egos to receive novel information. Diffusion of novel information to egos is a function of structure of their personal networks. Krackhardt and Stern (1988) and McGrath and Krackhardt (2003) extend this argument. They explore the composition of alters relative to egos in a personal network. An enabling composition of alter connections increase the likelihood of egos to act in light of this enhanced awareness level.

Findings from the study were in lines with Krackhardt and Stern (1988), McGrath and Krackhardt (2003), Miller and Mobarak (2015), and Mohammed (2001). Disparities existed between composition of personal networks of LPG adopters and non-LPG adopters. Key findings were: 1) personal networks of LPG adopters (both women and men) had significantly higher gender based homophily than that of non-LPG adopters (both women and men). Alters constituted a higher proportion of same gender as that of egos in the personal networks of LPG adopters compared to that of the non-LPG adopters; 2) personal networks of LPG adopters (both women and men) had

significantly higher proportion of alters, who also had adopted LPG. On the other hand, personal networks of non-LPG adopters (both women and men) had significantly higher proportion of alters, who also had not taken up LPG.

In gender and class segregated communities, behavior change has a higher likelihood to occur when there is more communication among community members (Deroïan, 2002; Kebede & Butterfield, 2009). Candid exchange of dialogue among community members increase when their personal networks are composed of alters sharing similar identities (same social status or same gender) (Harris et al., 2014; Mohammed, 2001; Ramirez et al., 2013). Higher homophily connect network members who are similar to one another, and who have shared partnerships with the same others in the network (Granovetter, 1983; Krackhardt, 1992; Valente, 2010). Higher homophily may not assist in dissemination of new information. However, higher homophily leads to greater levels of trust and candid conversations are relatively frequent. This is necessary to facilitate major behavioral change (Mohammed, 2001; Ramirez et al., 2013; Valente, 1996). This argument held a strong purchase in the findings of this study.

Adoption of LPG is a significant change in the "way of life" of rural poor. Verbal validation from peers with shared identities (same gender or LPG adoption status) helped shape decision of egos in the networks. LPG adopters had higher structural holes facilitating receipt of novel information. Once the information on technological innovation such as LPG "seeped in" these personal networks, higher homophily (gender and LPG adoption status) in personal networks of LPG adopters facilitated expedited actions (Tenkasi, 2003; Valente, 2010). Composition of personal network was conducive to impress a change among the LPG adopters. Alters of the LPG adopters (both women and men) had a significantly higher proportion, who also had adopted LPG. Motivation and peer pressure to adopt LPG in these egos was high as majority in their personal connections already owned LPG (Mohammed, 2001). "Domino effect" due to peer pressure from

their personal networks was strong for these egos (both women and men) to shift to LPG (Mohammed, 2001). A higher gender homophily lubricated this transition (Choi et al., 2010). With higher gender homophily (for both women and men in LPG adopter group), it was easier for these egos to engage in a more candid discussion and transparent dialogue about their perceptions on this behavioral shift on cooking. Thus, in lines with Mohammed (2001), Tenkasi and Chesmore (2003) there were two clear facilitators for LPG adoption in case group respondents (both women and men) of ego-network survey: 1) majority of the alter connections of the respondents had adopted LPG; and 2) a higher proportion of same gender as that of egos ensured more transparent and candid conversation on personal perceptions about behavioral shift on cooking. Both these factors created an enabling climate for the respondents to adopt LPG. Shared identities between alters and egos increases social influence on network members. This expedites or exacerbates their motivation to change (Mohammed, 2001). The two factors acting as facilitators for LPG adoption in case group respondents acted as barriers for non-LPG adopters (both women and men): 1) majority of the alter connections of these respondents still exclusively used traditional stoves, and had not adopted LPG. Compared to LPG adopters, non-LPG adopters were surrounded with alters who pre-dominantly were traditional stove users; and 2) these respondents had lower gender based homophily. Scope to engage in frequent and transparent conversations with people with similar identity (gender) was low. These barriers created a climate where motivation to transition was relatively lower. Lower gender based homophily further exacerbated this situation.

6.3 Overall analysis: Revisiting RE-AIM

The study began with a series of interrelated inquiries: 1) why do some BPL households take up cleaner cooking fuels while others from the same community do not? 2) Are there household, network, and organizational drivers that impact this choice? 3) Can these drivers be delineated clearly within the three concepts of affordability, accessibility, and awareness (3As) on cleaner

cooking fuels? 4) Can predictors related to these 3As be studied within the framework of RE-AIM implementation science evaluation framework to explore if these predictors concurrently impact adoption of cleaner cooking fuels in these BPL households? Using LPG as a representative cleaner cooking fuel, the study examined key elements of the RE-AIM evaluation framework to answer these inquiries.

Findings of the study showed that there are indeed household, organizational, and network drivers that enable adoption of LPG in BPL communities of rural India. These drivers could be systematically delineated as determinants classified within the three concepts of affordability, accessibility, and awareness. These determinants have a relative contribution to either act as enablers or as impediments of LPG adoption in these BPL households. As was expected, income was a crucial but a partial motivator of LPG adoption in BPL households. Controlling for demographic and 3As predictors, the study has conclusive evidence that multiple underexplored determinants significantly predicted adoption behavior of these households. For instance, the study provided evidence that availability of tarmac roads was crucial for LPG adoption. Availability of free biomass in the vicinity of these households deterred adoption of LPG. Perception of LPG explosion also deterred households to adopt LPG. However, attending in-person awareness campaigns clearly motivated households to adopt LPG.

Awareness building is also a function of structure and composition of personal networks of individuals. So, the study also explored this dimension of awareness. The study examined if personal networks of women and men could provide cues on their choice of adoption of LPG. The study validated few ego-network studies undertaken in other areas pertaining to adoption of technological innovation in resource constrained households. The study concluded that LPG men (compared to non-LPG men) had higher structural holes in their personal networks, which facilitated access to novel and disparate information. Also, LPG adopters (both women and men) had higher homophily

in gender and LPG adoption. LPG adopters (both women and men) had more people in their networks with shared identities and shared attributes. This type of network composition facilitated more engaged dialogue on their clean cooking adoption choices, and created an enabling environment for them to shift to LPG.

Implementation Science or the "science of delivery" studies multiple factors that are associated with adoption and sustained use of evidence-based research interventions in routine practices and policy (Brownson et al., 2012). Unless we address the challenges of evidence to practice gap, timely realization of the UN Global Goals will be difficult. The study provided a strong evidence that there are multiple and concurrent determinants of LPG adoption. Addressing all of these determinants in totality is crucial for fostering energy poor communities to adopt cleaner cooking systems such as LPG. Table 6 summarizes key elements from this study against each of the dimensions of the RE-AIM framework. Using the RE-AIM framework to undertake this study could serve two purposes: 1) factors analyzed against each of the RE-AIM dimensions could be examined in studies in other geographies on adoption and sustained use of cleaner cooking systems; and 2) factors could be tailored and tested in the adoption of other evidence-based interventions in routine practices of poor communities. For instance: sustained use of contraceptives in Uganda, toilets in Bangladesh, mosquito nets in parts of Africa, and mobile technologies in rural India.

Table 6: Summary of key elements of the study classified against the dimensions of RE-AIM framework

Reach: participation and representativeness of the target population for the intervention

- Respondents belonged to the BPL energy poor population of rural India.
- Detailed demographic analyses was conducted in the study
- Primary respondent was women of the household or the female primary cook of the household. Women are central to the pernicious impact of household air pollution.
- Women of the household and her spouse (or the male primary decision maker) of the household were respondents for personal gender based networks.

Effectiveness: success rate of health intervention, if implemented

- The evidence based technology in this study was LPG.
- The effectiveness of LPG has been established by the WHO.
- LPG meets all the required IAQG.

Adoption: proportion of target population taking up the intervention; determinants driving this uptake

- The study was undertaken with sample population from both LPG adopters and non-LPG adopters.
- Following determinants were associated with adoption of LPG:

Affordability	Accessibility	Awareness	
• Income of the respondent • Income of the household • Agricultural debt of the household	• Nearest tarmac road from the household • Availability of free biomass near the household • Distance of the biomass source	• Perception of LPG explosion on adoption • Campaigns attended	• Personal networks of respondents with shared identities (gender, LPG adoption status)

Implementation: the extent to which the intervention is implemented as intended in the real world

- The study examined two implementation related determinants from the users' perspective, which could impact LPG adoption.
- Both these determinants significantly impacted adoption of LPG. They are: 1) awareness campaigns undertaken by *gram panchayats* (local self-government) or governments; and 2) membership with SHGs.

Maintenance: Extent to which an intervention are sustained over time*

*This dissertation study, as part of the ISN grant, is confined to focus on determinants of adoption of LPG. Exploring maintenance of LPG and its determinants will succeed this dissertation study, but is beyond the scope of this current study.

6.4 Limitations

There are a number of limitations of this study. Each of these limitations is briefly considered below.

The study employed a retrospective design. The findings did not establish a causal relationship between independent and dependent variables.

The retrospective nature of the study for LPG adopters might have led to decreased validity of responses due to issues of memory retention. Recall bias might have limited the accuracy of participants' responses on factors of 3As which impact adoption. However, engaging a large sample size of 510 households for aim 1 and 361 households for aim 2 in such geographically proximal households might have reduced the issues of recall bias (Yin, 2013).

The 3As conceptual model was tested within the RE-AIM evaluation framework. Both adoption and sustained use of LPG could be a function of affordability, accessibility, and awareness of BPL rural communities on LPG. The study focused on the adoption component. The study did not explore the dimension of "maintenance" or sustained integration of LPG use in routine practices of these communities.

Multiple determinants each pertaining to affordability, accessibility, awareness were tested as predictors of LPG adoption. These determinants were collated from existing literature, anecdotal evidence, or policy reports. Questionnaires from DHS, Census of India, and National Sample Survey Organization were particularly useful. However, there is a strong likelihood that there might be additional predictors pertaining to these 3 concepts that might have not been tested in regression models. These additional factors could also have an impact on LPG adoption behavior of the BPL communities.

The RE-AIM evaluation framework invokes analyses at multiple levels. Both individual and community level determinants could impact LPG adoption. This study accounted for individual

level factors. The study explored only 35 habitations. Statistical power was low for a multilevel examination.

There is limited empirical evidence available on the impact of 3As on adoption of LPG. This study was primarily exploratory and developmental in nature. However, it is expected that this study will inform future efforts to develop and test the effectiveness of implementation strategies of LPG adoption and use in resource poor settings around the RE-AIM framework. In addition, findings from the study will provide insights on the estimate of effect size to facilitate a larger R01 study on the impact of 3As on LPG adoption and sustained use in such communities.

The study undertook personal network analyses in aim 2 to explore if gender based networks could be associated with LPG adoption behavior of BPL communities. The study focused on three compositional factors of personal networks: 1) gender; 2) caste; and 3) LPG adoption status. There could be additional compositional factors not included in the analyses. For instance: geographical distance of alters, age of alters, or educational attainment of alters. Additional compositional analyses of alters could have revealed more insights on LPG adoption behavior of the respondents.

The study did not undertake examination of multiple attributes of the same alters while undertaking personal network analyses. For instance: The study did investigate separately the gender, caste, and the LPG adoption status of alters separately. However, the analyses did not cover what is the gender, caste, and LPG adoption status of the same alters in question. Examining interaction of multiple compositional attributes for the same alter could reveal additional insights on LPG adoption behavior of the egos.

Despite these limitations, this study represents the: 1) first-ever systematic quantitative analyses examining concurrent impact of the 3As on LPG adoption; and 2) first-ever application of personal network analyses to explore if gender based networks could explain cleaner cooking adoption behavior of BPL communities in India. Researchers basing their future studies on these current

findings should be mindful of the limitations identified in this study, and incorporate suggestions for improvement.

6.5 Implications for policy and practice

The purpose of this study was to explore determinants of LPG adoption in BPL communities of rural India. Findings showed that in addition to income, there were multiple underexplored determinants that have an impact on LPG adoption. It is possible that the study might not have undertaken examination of additional predictors in clean cooking sector. We have a long way to go to ensure that the findings of this implementation research actually impact real world practice. Findings and results from this study still hold significance in informing implementation strategies for LPG dissemination and implementation. This discussion focuses on multiple implications of this study, which if implemented in real world scenario might help inching closer to bridging the evidence-translation gap in clean cooking adoption.

Implication 1: Lack of adequate affordability prevents LPG adoption. Social policy should cater to the affordability needs of BPL households.

To disseminate LPG in rural poor households, national governments such as that of India provide subsidies on LPG purchase. Bulk of the subsidy benefits in India, however, goes to the wealthier households. Estimates show that the richest 30% households in India receive more than 50% of subsidy benefits, while the poorest 30% receive a meagre 15% of the subsidy benefits (Jain et al., 2014). In the rural areas, the lowest income group decile spends around 8% of their monthly expenditure on LPG compared to a mere 3.3% by the highest income decile in rural areas (Jain et al., 2014). Skewed nature of subsidy benefits to richer households has been an outcome of the universal subsidy system practiced as a policy measure by the Government of India. The findings of this study showed that variation in income levels impact LPG adoption choices of poor households. Lower income is clearly an impediment in LPG adoption. The findings of this study align with an

increasing body of evidence advocating for overhaul in LPG subsidy system in India. Extent of subsidy benefits should increase for the poorer households of India. This additional financial burden on the government could be partially offset by reducing subsidies to the wealthier households. Differential subsidies (rather than a blanket or a universal subsidy system) on LPG based on household income might help in expanding the LPG cover to these BPL households. Simon et al. (2014) argue that the debate should not cling on objective choice of subsidy. Rather, social policy could be formulated to bolster capacity of households by providing them 'smart or differential subsidies' linked with extent of household's poverty. Smart subsidies can help reduce long-term unsustainable dependence on public exchequer (Simon et al., 2014).

Implication 2: Allied infrastructural bottlenecks hamper LPG adoption. An enabling infrastructural climate is crucial to increase accessibility to LPG distribution centers.

Findings showed that proximity to tarmac roads and to LPG distribution centers drive LPG adoption. This is of importance for habitations in rural interiors, most of which are invariably dominated by SC/ST population. Findings also showed that when all factors controlled for, SC/ST households are less likely to adopt LPG than general caste households. Development of infrastructure especially tarmac roads would boost connectivity. This would positively impact LPG adoption especially in SC/ST communities where there is relatively lower penetration of LPG. There is a cap to increasing the number of LPG distribution centers every year in India. The number is determined by the government budgets, which are often constrained. However, location of these distribution centers could be strategically determined to ensure relatively easier connectivity with the households located in rural interiors. This would not only enhance adoption, but might also improve sustained use of LPG.

Implication 3: Enhancing awareness motivates BPL households to adopt LPG. Targeted attempts must be made to increase social marketing campaigns to increase

awareness of pernicious health, environmental, and economic impact of perpetual biomass use.

These habitations had adequate access to media (radio and TV). Findings, however, clearly showed that in-person awareness campaigns impact the LPG adoption decision of households. Targeted social marketing campaigns implemented by the government, SHGs, or OMCs are crucial. There will be limited uptake of LPG unless the recent government schemes on Give it Up, PAHAL, or Ujjwala are strategically advertised at local level in these communities.

Implication 4: In a gender segregated social system, women's networks are critical for disseminating innovations especially at the community level.

Findings showed that homophilic social systems provide a scenario where the gendered nature of personal networks can be harnessed for a successful LPG dissemination strategy. Compositions of women's networks are focused more on the well-being of the family and kin (Moore, 1990). At a local level, women are more likely to have a stronger advice seeking personal relationships with the other women in the communities, which are closer to each other (Szell & Thurner, 2013). Greater success of women SHG systems and evidence of expeditious diffusion of other public health interventions through women's networks highlight its purchase to play a key role in fostering diffusion of LPG in multiple households.

Implication 5: Personal network analyses could be utilized to identify opinion leaders, who are influential in shaping the LPG adoption behavior of other members in their networks.

In a social system, presence of opinion leaders is as important as the existence of ties itself (Acemoglu et al., 2011). Personal network analyses could be used to identify local opinion leaders (Rangan et al., 2007). They can be instrumental in successfully disseminating awareness regarding the pernicious effect of using traditional stoves on their children and family members. Owing to a

stronger homophily in women's networks, the propensity of women members to emulate their influential opinion leaders is higher. This could be a significant dissemination strategy in poor rural habitations. This implication is in line with the role and influence of women's personal networks successfully harnessed by Unilever (HUL) to tap India's base-of-the-pyramid rural markets. An innovative business strategy adopted by the firm, it diffuses their consumer goods meant for the rural population through these opinion leaders or principal agents who exercise a domino effect on a homophilic social system. Project Shakti, initiated by Unilever, is a rural initiative that started in 2000 to increase penetration into the rural markets and at the same time to provide livelihood opportunities to rural women targeting small villages of low potentiality and low accessibility (Rangan et al., 2007; Xavier, Raja, & Nandhini, 2007). By identifying and selecting the influential women of the communities (designated as the Shakti Entrepreneurs or *'Shakti Ammas'*), these women members act as the nodal agent to influence the other women members in the communities to adopt the HUL consumer products meant for the rural markets of India (Rangan & Rajan, 2005).

Implication 6: Adoption of implementation science approach to explore cleaner cooking adoption and use could provide insights into effective scaling up strategies.

The Government of India has plans to adopt strategies to push LPG to the rural interiors of the country. Scale up of interventions merit thorough understanding of the efficacy of the factors, which could impact LPG adoption.

Yamey (2012) argues that a successful scale-up is less likely if the intervention is complex. The current study utilized the RE-AIM framework to examine predictors, which could bolster a successful LPG dissemination strategy. A direct implication of this study is to build evidence that scaling up of an efficacious intervention is possible if the complexity of intervention is reduced. Systematic implementation within a conceptual framework with simplified rules and procedures might assist in effective scale up (McCannon, Berwick, & Massoud, 2007).

Yamey (2012) argues that a successful scale up requires a nuanced understanding of multiple factors impacting the intervention. This study was situated within the domain of implementation science, and employed RE-AIM framework to systematically explore the factors impacting adoption of LPG. The study examined multiple household, organizations, and network related drivers that could enable LPG adoption. These factors could be tested in multiple geographies to strengthen the evidence base for scaling up LPG dissemination.

Yamey (2012) argues that a successful scale requires leaders at macro and micro level, who could drive the implementation process. This study adopted ego network analyses to examine structural and compositional characteristics of personal networks of study participants. Network analyses could be utilized to identify opinion leaders at micro level in communities, who could be pivotal in pushing the LPG cooking systems deeper in the communities.

6.6 Implications for continued research

The findings of this study provide scope for exploring more interrelated questions in the household air pollution sector. This study was able to tested a component of the larger RE-AIM evaluation framework. Only LPG adoption was conceptualized as a function of affordability, accessibility, and awareness on LPG by rural poor. While this study laid a foundation in three aspects: 1) quantitative analyses on determinants of LPG adoption; 2) personal network analyses to explore if gender based networks could characterize LPG adoption behavior of BPL habitations; and, 3) conceptualization within the RE-AIM implementation science evaluation framework; still the study raises multiple implications for continued research. These are discussed below.

Implication 1: Explore "maintenance" dimension of the RE-AIM framework in the clean cooking sector.

Adoption is a crucial dimension of the RE-AIM framework, which was addressed in this study. However, RE-AIM's maintenance component or the extent to which an intervention is sustained

over time is equally significant and merits systematic investigation. Although it was not a part of this study, examination of factors impacting sustained use of LPG is underway as part of the larger ISN grant. This study immediately succeeds the current research on adoption of LPG. This study determines if affordability, accessibility, and awareness affect sustained use of LPG in adopter households. The study is currently conducting real time monitoring of LPG stoves and traditional stoves in these 60 households by deploying the stove use monitoring systems (SUMS) technology, which can provide accurate data on the degree of use of stoves. SUMS are low-cost commercially available temperature loggers and are provided with customized software. By recording stove temperature, SUMS provides accurate insights into usage patterns, number of meals cooked per day, and time of use per day on each of these stoves on which SUMS are installed (Ruiz-Mercado et al., 2013). SUMS data have stronger validity than self-reported values on the degree of stove use.

Figure 21: Stove use monitor systems (BerkeleyAir, 2016)

Implication 2: Examination of interaction effects on LPG adoption could lead to additional insights.

Interaction effects of multiple predictors were not controlled for in the regression models analyzed in this study. For instance: it was observed that both income of the household and agricultural debt significantly predicted LPG adoption. It would be interesting to analyze the impact of relatively poorer households with higher agricultural debt or relatively wealthier households with

lower agricultural debt. Adding such interaction variables to regression models can expand understanding of the relationships among the variables pertaining to affordability, accessibility, and awareness. This would allow additional hypotheses to be tested informing more insights in clean cooking adoption.

Implication 3: Explore alternative research designs to understand factors associated with adoption and sustained use of cleaner cooking systems.

Case control designs such as the current study are retrospective, and have a higher likelihood to be afflicted with recall bias. The findings of this study provide insights on crucial factors impacting adoption of cleaner cooking systems. To further build the evidence based scholarship in this area, the current study should precede larger longitudinal studies. The longitudinal studies are less impacted by recall bias. Longitudinal studies can examine factors impacting LPG adoption and sustained use at both the group and the individual level beyond a single moment in time. Therefore, they can establish cause and effect relationship absent in the current study design.

The majority of the literature employs a linear approach to understand the determinants of clean cooking adoption and sustained use. Study designs employing a non-linear approach are rare. Theoretical analyses of co-production, structuration model, and social capital establish that there is an interaction between social system and its agents. The change in social modalities (elevation of communities on the energy ladder) is a result of interactions among the sub-systems of communities. Innovative research designs using system sciences such as social network analysis could be employed to explore how social system impacts individuals' behavior of LPG adoption and use. The study investigated structure and composition of the networks of LPG and non-LPG adopters. Further analyses could be undertaken in relation to the alter characteristics, which includes age, geographical distance from the egos, membership with SHGs, educational status, and income.

Implication 4: Conduct multilevel analyses of the determinants of LPG adoption and use.

The RE-AIM framework advocates for analyses of health interventions at multiple levels focusing both on individual and community or organizational levels. The current study tested hypotheses, which were at individual level. There were a total of 35 habitations covered in this study. Relatively smaller number of habitations covered in the current study prevented multilevel analyses. Cleaner cooking adoption is also impacted by community and state level factors. Thus, the study provides a precedence to test multilevel level impacts on LPG adoption.

Implication 5: Explore the supply-side perspective on determinants of LPG adoption and use within the RE-AIM framework.

The study was based on the RE-AIM framework. The implementation component of the RE-AIM is a function of the fidelity to public health interventions. In other words, data for implementation encompasses perspective of: 1) organizations responsible for effective delivery of these government schemes/interventions; and 2) project participants on whether the services are being delivered in a way it was purported to be delivered. The study collected data from the consumers' side. Perspective for implementation was examined from the consumers' point of view. However, the study did not collect data from organizations (or supply side perspective) on implementation. These organizations could be local LPG distribution agencies, OMCs, and district administration.

Implication 6: Explore model smokeless habitations in rural India to gain insights on how communities could make a complete transition to clean cooking

Clean cooking adoption studies should be complemented by undertaking case studies on model habitations, which have gone smokeless. Another piece of research that could germinate from the current study is to investigate a case of a model smokeless village. Bysanivaripalle in Chittoor

district of Andhra Pradesh is a small habitation that has 36 families, but has gained a huge reputation due to its complete shift to cleaner cooking systems for their routine activities. The eco-consciousness of these villagers is appreciated throughout the world as they established the first biogas plant in their village nearly two decades ago.

6.7 Concluding remarks

This chapter: 1) analyzed the findings and results from the previous chapter; 2) discussed that the 3As indeed impacts LPG adoption status of BPL communities; 3) highlighted that personal gender based networks matter in LPG adoption behavior of communities; and 4) provided an overall analyses of the findings under the lens of the RE-AIM framework, which was instrumental in conceptualizing this study, constructing research instruments, and subsequent analyses. The current study has significant implications for practitioners, who strive to address the challenge of household air pollution. Finally, the chapter also discussed ample outlets of further research directly based on the findings of this study, which will further build the evidence based scholarship crucial to address the challenge of household air pollution.

VII. References

Abou-Zeid, E.-S. (2007). A theory-based approach to the relationship between social capital and communities of practice. *Electronic Journal of Knowledge Management, 5*(3), 257-264.

Acemoglu, D., Ozdaglar, A., & Yildiz, E. (2011). Diffusion of innovations in social networks. *2011 50th IEEE Conference on Decision and Control and European Control Conference (CDC-ECC 2011)*, 2329-2334. doi:10.1109/cdc.2011.6160999

Adler, P. S., & Kwon, S.-W. (2002). Social capital: Prospects for a new concept. *Academy of Management Review, 27*(1), 17-40.

Ahuja, G. (2000). Collaboration networks, structural holes, and innovation: A longitudinal study. *Administrative Science Quarterly, 45*(3), 425-455.

Ali, I. (2007). Inequality and the imperative for inclusive growth in Asia. *Asian Development Review, 24*(2), 1.

Anheier, H. K., Gerhards, J., & Romo, F. P. (1995). Forms of capital and social structure in cultural fields: Examining Bourdieu's social topography. *American journal of Sociology*, 859-903.

Bailis, R., Cowan, A., Berrueta, V., & Masera, O. (2009). Arresting the Killer in the Kitchen: The Promises and Pitfalls of Commercializing Improved Cookstoves. *World Development, 37*(10), 1694-1705. doi:http://dx.doi.org/10.1016/j.worlddev.2009.03.004

Barnes, D. F., Openshaw, K., Smith, K. R., Van der Plas, R., & Mundial, B. (1994). *What Makes People Cook with Improved Biomas Stoves?* : Banco Mundial.

BerkeleyAir. (2016). Stove Use Monitoring System (SUMS). Retrieved from http://berkeleyair.com/services/stove-use-monitoring-system-sums/

Bhojvaid, V., Jeuland, M., Kar, A., Lewis, J., Pattanayak, S., Ramanathan, N., . . . Rehman, I. (2014). How do People in Rural India Perceive Improved Stoves and Clean Fuel? Evidence from Uttar Pradesh and Uttarakhand. *International Journal of Environmental Research and Public Health, 11*(2), 1341.

Bonjour, S., Adair-Rohani, H., Wolf, J., Bruce, N. G., Mehta, S., Prüss-Ustün, A., . . . Smith, K. R. (2013). Solid Fuel Use for Household Cooking: Country and Regional Estimates for 1980-2010. *Environmental Health Perspectives, 121*(7), 784-790. doi:10.1289/ehp.1205987

Bourdieu, P. (1985). The social space and the genesis of groups. *Theory and Society, 14*(6), 723-744. doi:10.1007/BF00174048

Brauer, M., Freedman, G., Frostad, J., van Donkelaar, A., Martin, R. V., Dentener, F., . . . Cohen, A. (2016). Ambient Air Pollution Exposure Estimation for the Global Burden of Disease 2013. *Environmental Science & Technology, 50*(1), 79-88. doi:10.1021/acs.est.5b03709

Brown, L. D., & Ashman, D. (1996). Participation, social capital, and intersectoral problem solving: African and Asian cases. *World Development, 24*(9), 1467-1479. doi:http://dx.doi.org/10.1016/0305-750X(96)00053-8

Brownson, R. C., Colditz, G. A., & Proctor, E. K. (2012). *Dissemination and implementation research in health: translating science to practice*: Oxford University Press.

Burnett, R. T., Pope III, C. A., Ezzati, M., Olives, C., Lim, S. S., Mehta, S., . . . Brauer, M. (2014). An integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. *Environmental Health Perspectives (Online), 122*(4), 397.

Burt, R. S. (1980). Innovation as a structural interest: rethinking the impact of network position on innovation adoption. *Social Networks, 2*(4), 327-355. doi:http://dx.doi.org/10.1016/0378-8733(80)90002-7

Burt, R. S. (1984). Network items and the general social survey. *Social Networks, 6*(4), 293-339. doi:http://dx.doi.org/10.1016/0378-8733(84)90007-8

Burt, R. S. (2001). Structural holes versus network closure as social capital. *Social capital: Theory and research*, 31-56.

Burt, R. S. (2009). *Structural holes: The social structure of competition*: Harvard university press.

Büttner, K., Scheffler, K., Czycholl, I., & Krieter, J. (2015). Social network analysis - centrality parameters and individual network positions of agonistic behavior in pigs over three different age levels. *SpringerPlus, 4*, 185. doi:10.1186/s40064-015-0963-1

Cecelski, E. (2000). *The role of women in sustainable energy development* (NREL/SR-550-26889). Retrieved from Colorado:

Choi, H., Kim, S.-H., & Lee, J. (2010). Role of network structure and network effects in diffusion of innovations. *Industrial Marketing Management, 39*(1), 170-177. doi:http://dx.doi.org/10.1016/j.indmarman.2008.08.006

Chung, K. S. K. (2009). *Understanding attitudes towards performance in knowledge-intensive work: the influence of social networks and ICT use.* (PhD), University of Sydeny, Sydney.

Coleman, J. S. (1988). Social capital in the creation of human capital. *American journal of Sociology*, S95-S120.

Curran, G. M., Bauer, M., Mittman, B., Pyne, J. M., & Stetler, C. (2012). Effectiveness-implementation Hybrid Designs: Combining Elements of Clinical Effectiveness and Implementation Research to Enhance Public Health Impact. *Medical care, 50*(3), 217-226. doi:10.1097/MLR.0b013e3182408812

Damschroder, L. J., Aron, D. C., Keith, R. E., Kirsh, S. R., Alexander, J. A., & Lowery, J. C. (2009). Fostering implementation of health services research findings into practice: a consolidated framework for advancing implementation science. *Implement Sci, 4*.

Damte, A., & Koch, S. F. (2011). *Clean fuel saving technology adoption in urban Ethiopia*. Retrieved from

Delre, S. A., Jager, W., Bijmolt, T. H. A., & Janssen, M. A. (2010). Will It Spread or Not? The Effects of Social Influences and Network Topology on Innovation Diffusion. *Journal of Product Innovation Management, 27*(2), 267-282. doi:10.1111/j.1540-5885.2010.00714.x

Deroïan, F. (2002). Formation of social networks and diffusion of innovations. *Research Policy, 31*(5), 835-846. doi:http://dx.doi.org/10.1016/S0048-7333(01)00147-0

Dhand, A., Luke, D. A., Lang, C. E., & Lee, J.-M. (2016). Social networks and neurological illness. *Nat Rev Neurol, 12*(10), 605-612. doi:10.1038/nrneurol.2016.119

http://www.nature.com/nrneurol/journal/v12/n10/abs/nrneurol.2016.119.html#supplementary-information

Durlak, J. A., & DuPre, E. P. (2008). Implementation matters: a review of research on the influence of implementation on program outcomes and the factors affecting implementation. *Am J Community Psychol, 41*.

Eccles, M. P., & Mittman, B. S. (2006). Welcome to implementation science. *Implement Sci, 1*.

Edwards, J. H. Y., & Langpap, C. (2005). Startup Costs and the Decision to Switch from Firewood to Gas Fuel. *Land Economics, 81*(4), 570-586. doi:10.3368/le.81.4.570

El Tayeb Muneer, S., & Mukhtar Mohamed, E. W. (2003). Adoption of biomass improved cookstoves in a patriarchal society: an example from Sudan. *Science of The Total Environment, 307*(1–3), 259-266. doi:http://dx.doi.org/10.1016/S0048-9697(02)00541-7

Fixsen, D. L., Naoom, S. F., Blase, K. A., Friedman, R. M., & Wallace, F. (2005). *Implementation Research: A Synthesis of the Literature*. Tampa, FL: University of South Florida, Louis de la Parte Florida Mental Health Institute.

GACC. (2011). *Igniting Change: A Strategy for Universal Adoption of Clean Cookstoves and Fuels*. Retrieved from Washington, DC: Retrieved from http://www.cleancookstoves.org/resources/fact-sheets/igniting-change.pdf

GACC. (2015). Defining and Measuring 'Adoption' of Clean Cookstoves and Fuels. Retrieved from http://cleancookstoves.org/about/news/05-22-2015-defining-and-measuring-adoption-of-clean-cookstoves-and-fuels.html

GACC. (2016). How do we define and measure adoption? Retrieved from http://cleancookstoves.org/about/news/02-18-2016-how-do-we-define-and-measure-adoption.html

Ganesan, K., & Vishnu, R. (2014). *Energy Access in India-Today, and Tomorrow*. Retrieved from http://ceew.in/pdf/CEEW-Energy-Access-in-India-Today-and-Tomorrow-1Jul14.pdf

Geremew, K., Gedefaw, M., Dagnew, Z., & Jara, D. (2014). Current Level and Correlates of Traditional Cooking Energy Sources Utilization in Urban Settings in the Context of Climate Change and Health, Northwest Ethiopia: A Case of Debre Markos Town. *BioMed Research International, 2014*, 572473. doi:10.1155/2014/572473

Giddens, A. (1990). Structuration theory and sociological analysis. *Anthony Giddens: consensus and controversy, 1*, 297-315.

Giddens, A. (1991). Structuration theory. *Past, present and future. I Christopher G. A Bryant & Jary David, red: Giddens' Theory of Structuration. A Critical Appreciation. London: Routledge*, 210-221.
Giddens, A. (1993). *New rules of sociological method: A positive critique of interpretative sociologies*: Stanford University Press.
Giddens, A. (2013). *The constitution of society: Outline of the theory of structuration*: John Wiley & Sons.
GIZ. (2014). Use of improved cookstoves can save many lives in India – India Clean Cookstove Forum 2014. Retrieved from http://www.giz.de/en/worldwide/28483.html
Glasgow, R. E., & Emmons, K. M. (2007). How can we increase translation of research into practice? Types of evidence needed. *Annu Rev Public Health, 28*. doi:10.1146/annurev.publhealth.28.021406.144145
Glasgow, R. E., Lichtenstein, E., & Marcus, A. C. (2003). Why Don't We See More Translation of Health Promotion Research to Practice? Rethinking the Efficacy-to-Effectiveness Transition. *American Journal of Public Health, 93*(8), 1261-1267.
Glasgow, R. E., Vogt, T. M., & Boles, S. M. (1999). Evaluating the public health impact of health promotion interventions: the RE-AIM framework. *Am J Public Health, 89*. doi:10.2105/ajph.89.9.1322
GoI. (2011). Census 2011. Retrieved from http://censusindia.gov.in/2011-prov-results/paper2/data_files/india/Rural_Urban_2011.pdf
Granovetter, M. (1983). The strength of weak ties: A network theory revisited. *Sociological theory, 1*(1), 201-233.
Granovetter, M. (1985). Economic Action and Social Structure: The Problem of Embeddedness. *American journal of Sociology, 91*(3), 481-510.
Harris, J. K., Baker, E. A., Radvanyi, C., Barnidge, E., Motton, F., & Rose, F. (2014). Employment Networks in a High-Unemployment Rural Area. *Connections (02261766), 34*.
Heltberg, R. (2005). Factors determining household fuel choice in Guatemala. *Environment and Development Economics, 10*(03), 337-361. doi:doi:10.1017/S1355770X04001858
Hollada, J., Williams, K., Miele, C., Danz, D., Harvey, S., & Checkley, W. (2017). Perceptions of Improved Biomass and Liquefied Petroleum Gas Stoves in Puno, Peru: Implications for Promoting Sustained and Exclusive Adoption of Clean Cooking Technologies. *International Journal of Environmental Research and Public Health, 14*(2), 182.
IndianExpress. (2011). CM wants 8 lakh LPG connections allotted to AP. Retrieved from http://www.newindianexpress.com/states/andhra_pradesh/article485367.ece
Jain, A., & Agrawal, S. *Improving Effectiveness of Domestic LPG Subsidy and Distribution in India*. Retrieved from
Jain, A., Agrawal, S., & Ganesan, K. (2014). *Rationalising Subsidies, Reaching the Underserved*. Retrieved from New Delhi: http://ceew.in/pdf/CEEW-Rationalising-LPG-Subsidies-Reaching-the-Underserved-5Dec14.pdf
Jauregui, E., Pacheco, A. M., Soltero, E. G., O'Connor, T. M., Castro, C. M., Estabrooks, P. A., . . . Lee, R. E. (2015). Using the RE-AIM framework to evaluate physical activity public health programs in México. *BMC Public Health, 15*(1), 1-9. doi:10.1186/s12889-015-1474-2
Jones, M. R., & Karsten, H. (2008). GIDDENS'S STRUCTURATION THEORY AND INFORMATION SYSTEMS RESEARCH. *MIS Quarterly, 32*(1), 127-157.
Kanagawa, M., & Nakata, T. (2008). Assessment of access to electricity and the socio-economic impacts in rural areas of developing countries. *Energy Policy, 36*(6), 2016-2029. doi:http://dx.doi.org/10.1016/j.enpol.2008.01.041
Kebede, W., & Butterfield, A. K. (2009). Social networks among poor women in Ethiopia. *International Social Work, 52*(3), 357-374.
Koorts, H., & Gillison, F. (2015). Mixed method evaluation of a community-based physical activity program using the RE-AIM framework: practical application in a real-world setting. *BMC Public Health, 15*, 1102. doi:10.1186/s12889-015-2466-y
Krackhardt, D. (1992). The strength of strong ties: The importance of philos in organizations. *Networks and organizations: Structure, form, and action, 216*, 239.
Krackhardt, D., & Stern, R. N. (1988). Informal Networks and Organizational Crises: An Experimental Simulation. *Social Psychology Quarterly, 51*(2), 123-140. doi:10.2307/2786835

Kumar, P., Kaushalendra Rao, R., & Reddy, N. H. (2016). Sustained uptake of LPG as cleaner cooking fuel in rural India: Role of affordability, accessibility, and awareness. *World Development Perspectives, 4*, 33-37. doi:http://dx.doi.org/10.1016/j.wdp.2016.12.001

Kumar, P., & Mehta, S. (2016). Poverty, gender, and empowerment in sustained adoption of cleaner cooking systems: Making the case for refined measurement. *Energy Research & Social Science, 19*, 48-52. doi:http://dx.doi.org/10.1016/j.erss.2016.05.018

Leach, G. (1992). Energy and the Third WorldThe energy transition. *Energy Policy, 20*(2), 116-123. doi:http://dx.doi.org/10.1016/0301-4215(92)90105-B

Lewis, Bhojvaid, V., Brooks, N., Das, I., Jeuland, M. A., Patange, O., & Pattanayak, S. K. (2015). Piloting Improved Cookstoves in India. *Journal of Health Communication, 20*(sup1), 28-42. doi:10.1080/10810730.2014.994243

Lewis, & Pattanayak. (2012). Who adopts improved fuels and cookstoves? A systematic review. *Environmental Health Perspectives, 120*(5), 637-645. doi:http://dx.doi.org/10.1289/ehp.1104194

Lewis, J. J., Hollingsworth, J. W., Chartier, R. T., Cooper, E. M., Foster, W. M., Gomes, G. L., . . . Pattanayak, S. K. (2017). Biogas Stoves Reduce Firewood Use, Household Air Pollution, and Hospital Visits in Odisha, India. *Environmental Science & Technology, 51*(1), 560-569. doi:10.1021/acs.est.6b02466

Lewis, J. J., & Pattanayak, S. K. (2012). Who adopts improved fuels and cookstoves? A systematic review. *Environmental Health Perspectives, 120*(5), 637.

Livemint, T. (2016). Union budget 2016-17: Rs2,000 crore for rural cooking gas connections. Retrieved from http://www.livemint.com/Politics/VIl11abBuw0Jo0KD244ibP/Union-budget-Rs2000-crore-for-rural-cooking-gas-connection.html

Loury, G. (1977). A dynamic theory of racial income differences. *Women, minorities, and employment discrimination, 153*, 86-153.

Lozares, C., Verd, J. M., Cruz, I., & Barranco, O. (2014). Homophily and heterophily in personal networks. From mutual acquaintance to relationship intensity. *Quality & Quantity, 48*(5), 2657-2670. doi:10.1007/s11135-013-9915-4

Lucon, O., Coelho, S. T., & Goldemberg, J. (2004). LPG in Brazil: lessons and challenges. *Energy for Sustainable Development, 8*(3), 82-90. doi:http://dx.doi.org/10.1016/S0973-0826(08)60470-6

Luke, D. (2012). Viewing dissemination through a network lens. *Dissemination and implementation research in health: translating science to practice, Oxford University Press, New York NY*, 154-174.

Martin, W. J., II, Glass, R. I., Balbus, J. M., & Collins, F. S. (2011). A major environmental cause of death. *Science (Washington), 334*(6053), 180-181. doi: doi:10.1126/science.1213088

Masera, O. R., Saatkamp, B. D., & Kammen, D. M. (2000). From linear fuel switching to multiple cooking strategies: a critique and alternative to the energy ladder model. *World Development, 28*(12), 2083-2103.

McCannon, C., Berwick, D. M., & Massoud, M. (2007). The science of large-scale change in global health. *JAMA, 298*(16), 1937-1939. doi:10.1001/jama.298.16.1937

McGrath, C., & Krackhardt, D. (2003). Network Conditions for Organizational Change. *The Journal of Applied Behavioral Science, 39*(3), 324-336. doi:10.1177/0021886303258267

Miller, G., & Mobarak, A. M. (2015). Learning About New Technologies Through Social Networks: Experimental Evidence on Nontraditional Stoves in Bangladesh. *Marketing Science, 34*(4), 480-499. doi:10.1287/mksc.2014.0845

Mohammed, S. (2001). Personal communication networks and the effects of an entertainment-education radio soap opera in Tanzania. *Journal of Health Communication, 6*(2), 137-154.

Moore, G. (1990). Structural determinants of men's and women's personal networks. *American sociological review*, 726-735.

Morrow-Howell, N., & Proctor, E. (1993). The Use of Logistic Regression in Social Work Research. *Journal of Social Service Research, 16*(1-2), 87-104. doi:10.1300/J079v16n01_05

Nahapiet, J., & Ghoshal, S. (1998). Social Capital, Intellectual Capital, and the Organizational Advantage. *Academy of Management Review, 23*(2), 242-266. doi:10.5465/amr.1998.533225

Neta, G., Glasgow, R. E., Carpenter, C. R., Grimshaw, J. M., Rabin, B. A., Fernandez, M. E., & Brownson, R. C. (2015). A Framework for Enhancing the Value of Research for Dissemination and Implementation. *Am J Public Health, 105*(1), 49-57. doi:10.2105/ajph.2014.302206

Nicholls, A., & Cho, A. H. (2006). Social entrepreneurship: The structuration of a field. *Social entrepreneurship: New models of sustainable social change*, 99-118.
Nilsen, P. (2015). Making sense of implementation theories, models and frameworks. *Implementation Science, 10*(1), 1-13. doi:10.1186/s13012-015-0242-0
O'Malley, A. J., Arbesman, S., Steiger, D. M., Fowler, J. H., & Christakis, N. A. (2012). Egocentric Social Network Structure, Health, and Pro-Social Behaviors in a National Panel Study of Americans. *PLoS ONE, 7*(5), e36250. doi:10.1371/journal.pone.0036250
O'malley, A. J., Arbesman, S., Steiger, D. M., Fowler, J. H., & Christakis, N. A. (2012). Egocentric social network structure, health, and pro-social behaviors in a national panel study of Americans.
Onyx, J., & Bullen, P. (2000). Measuring Social Capital in Five Communities. *The Journal of Applied Behavioral Science, 36*(1), 23-42. doi:10.1177/0021886300361002
Pachauri, S., Mueller, A., Kemmler, A., & Spreng, D. (2004). On Measuring Energy Poverty in Indian Households. *World Development, 32*(12), 2083-2104. doi:http://dx.doi.org/10.1016/j.worlddev.2004.08.005
Pachauri, S., & Rao, N. D. (2013). Gender impacts and determinants of energy poverty: are we asking the right questions? *Current Opinion in Environmental Sustainability, 5*(2), 205-215. doi:http://dx.doi.org/10.1016/j.cosust.2013.04.006
Pine, K., Edwards, R., Masera, O., Schilmann, A., Marrón-Mares, A., & Riojas-Rodríguez, H. (2011). Adoption and use of improved biomass stoves in Rural Mexico. *Energy for Sustainable Development, 15*(2), 176-183. doi:http://dx.doi.org/10.1016/j.esd.2011.04.001
Portes, A. (2000). Social capital: Its origins and applications in modern sociology. *LESSER, Eric L. Knowledge and Social Capital. Boston: Butterworth-Heinemann*, 43-67.
Press, S. J., & Wilson, S. (1978). Choosing between Logistic Regression and Discriminant Analysis. *Journal of the American Statistical Association, 73*(364), 699-705. doi:10.1080/01621459.1978.10480080
Putnam, R. D. (1995). Bowling alone: America's declining social capital. *Jouenal of Democeacy, 6*, 68.
Rajakutty, S., & Kojima, M. (2002). Promoting clean household fuels among the rural poor: Evaluation of the Deepam Scheme in Andhra Pradesh. *World Bank Report No. IDP-183*.
Ramirez, S., Dwivedi, P., Ghilardi, A., & Bailis, R. (2013). Diffusion of non-traditional cookstoves across western Honduras: A social network analysis. *Energy Policy*.
Rangan, V. K., & Rajan, R. (2005). Unilever in India: Hindustan Lever's Project Shakti—Marketing FMCG to the Rural Consumer. *Harvard Business School case*(9-505), 056.
Rangan, V. K., Sehgal, D., Rajan, R., Quelch, J., Herrero, G., & Barton, B. (2007). The complex business of serving the poor: insights from Unilever's project Shakti in India. *Business solutions for the global poor: creating social and economic value*, 144-154.
Rhodes, E. L., Dreibelbis, R., Klasen, E., Naithani, N., Baliddawa, J., Menya, D., . . . Checkley, W. (2014). Behavioral Attitudes and Preferences in Cooking Practices with Traditional Open-Fire Stoves in Peru, Nepal, and Kenya: Implications for Improved Cookstove Interventions. *International Journal of Environmental Research and Public Health, 11*(10), 10310-10326. doi:10.3390/ijerph111010310
Ridley-Duff, R., & Bull, M. (2011). *Understanding social enterprise: Theory and practice*: Sage Publications.
Rogers, E. M. (1983). *Diffusion of innovations* (3rd ed ed.). New York :London: Free Press ;Collier Macmillan.
Rogers, E. M. (2004). A prospective and retrospective look at the diffusion model. *Journal of Health Communication, 9*(S1), 13-19.
Rogers, E. M., Medina, U. E., Mario, M. A., & Wiley, C. J. (2005). Complex Adoptive Systems and the Diffusion of Innovations. *The Public Sector Innovation Journal, 10*(3).
Rose, J. (1999). *Towards a structurational theory of IS, theory development and case study illustrations.* Paper presented at the Proceedings of the 7th European conference on information systems, Copenhagen.
Ruiz-Mercado, I., Canuz, E., Walker, J. L., & Smith, K. R. (2013). Quantitative metrics of stove adoption using Stove Use Monitors (SUMs). *Biomass and Bioenergy, 57*, 136-148. doi:http://dx.doi.org/10.1016/j.biombioe.2013.07.002
Ruiz-Mercado, I., Masera, O., Zamora, H., & Smith, K. R. (2011). Adoption and sustained use of improved cookstoves. *Energy Policy, 39*(12), 7557-7566.
Sagar, A. D. (2005). Alleviating energy poverty for the world's poor. *Energy Policy, 33*(11), 1367-1372.

Sarason, Y., Dean, T., & Dillard, J. F. (2006). Entrepreneurship as the nexus of individual and opportunity: A structuration view. *Journal of Business Venturing, 21*(3), 286-305. doi:http://dx.doi.org/10.1016/j.jbusvent.2005.02.007

Sehjpal, R., Ramji, A., Soni, A., & Kumar, A. (2014). Going beyond incomes: Dimensions of cooking energy transitions in rural India. *Energy, 68*, 470-477. doi:http://dx.doi.org/10.1016/j.energy.2014.01.071

Shrimali, G., Slaski, X., Thurber, M. C., & Zerriffi, H. (2011). Improved stoves in India: A study of sustainable business models. *Energy Policy, 39*(12), 7543-7556.

Simon, G. L., Bailis, R., Baumgartner, J., Hyman, J., & Laurent, A. (2014). Current debates and future research needs in the clean cookstove sector. *Energy for Sustainable Development, 20*(0), 49-57. doi:http://dx.doi.org/10.1016/j.esd.2014.02.006

Slaski, X., & Thurber, M. (2009a). Research note: cookstoves and obstacles to technology adoption by the poor. Stanford, CA: Program on Energy and Sustainable Development: Stanford Program on Energy and Sustainable Development Working Paper No. 89.

Slaski, X., & Thurber, M. (2009b). Research note: cookstoves and obstacles to technology adoption by the poor. *Program on energy and sustainable development, working paper, 89*.

Smith, K. R., Bruce, N., Balakrishnan, K., Adair-Rohani, H., Balmes, J., Chafe, Z., . . . Rehfuess, E. (2014). Millions Dead: How Do We Know and What Does It Mean? Methods Used in the Comparative Risk Assessment of Household Air Pollution. *Annual Review of Public Health, 35*, 185-206. doi:10.1146/annurev-publhealth-032013-182356

Smith, K. R., & Mehta, S. (2003). The burden of disease from indoor air pollution in developing countries: comparison of estimates. *International journal of hygiene and environmental health, 206*(4), 279-289.

Smith, K. R., & Sagar, A. (2014). Making the clean available: Escaping India's Chulha Trap. *Energy Policy, 75*(0), 410-414. doi:http://dx.doi.org/10.1016/j.enpol.2014.09.024

Song, J. W., & Chung, K. C. (2010). Observational Studies: Cohort and Case-Control Studies. *Plastic and reconstructive surgery, 126*(6), 2234-2242. doi:10.1097/PRS.0b013e3181f44abc

Szell, M., & Thurner, S. (2013). How women organize social networks different from men. *Scientific reports, 3*.

Tabak, R. G., Khoong, E. C., Chambers, D. A., & Brownson, R. C. (2012). Bridging research and practice: models for dissemination and implementation research. *American Journal of Preventive Medicine, 43*(3), 337-350.

Tenkasi, R. V., & Chesmore, M. C. (2003). Social Networks and Planned Organizational Change The Impact of Strong Network Ties on Effective Change Implementation and Use. *The Journal of Applied Behavioral Science, 39*(3), 281-300.

Tripathi, A., Sagar, A. D., & Smith, K. R. (2015). Promoting Clean and Affordable Cooking. *Economic & Political Weekly, 50*(48), 81.

UN. (2015a). Energy Statistics Database. Retrieved from http://knoema.com/UNSDESD2015/un-statistics-division-energy-statistics-database-2015?location=1000340-cambodia

UN. (2015b). Sustainable Development Goals. Retrieved from http://www.un.org/sustainabledevelopment/

Valente, T. W. (1996). Social network thresholds in the diffusion of innovations. *Social Networks, 18*(1), 69-89.

van der Kroon, B., Brouwer, R., & van Beukering, P. J. H. (2013). The energy ladder: Theoretical myth or empirical truth? Results from a meta-analysis. *Renewable and Sustainable Energy Reviews, 20*, 504-513. doi:http://dx.doi.org/10.1016/j.rser.2012.11.045

Venkataraman, C., Sagar, A., Habib, G., Lam, N., & Smith, K. (2010). The Indian national initiative for advanced biomass cookstoves: the benefits of clean combustion. *Energy for Sustainable Development, 14*(2), 63-72.

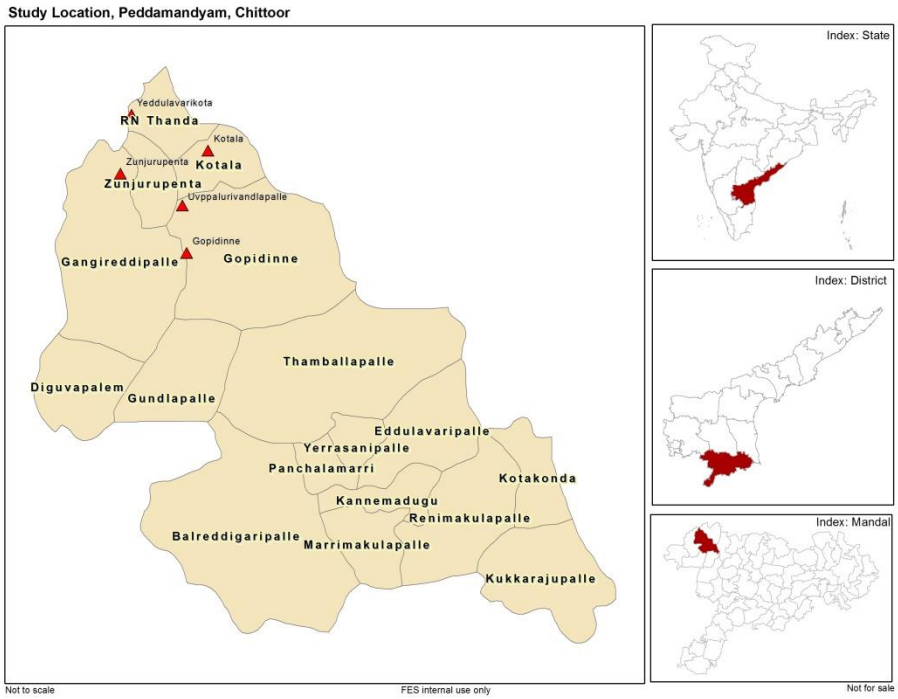
Viswanathan, B., & Kavi Kumar, K. S. (2005). Cooking fuel use patterns in India: 1983–2000. *Energy Policy, 33*(8), 1021-1036. doi:http://dx.doi.org/10.1016/j.enpol.2003.11.002

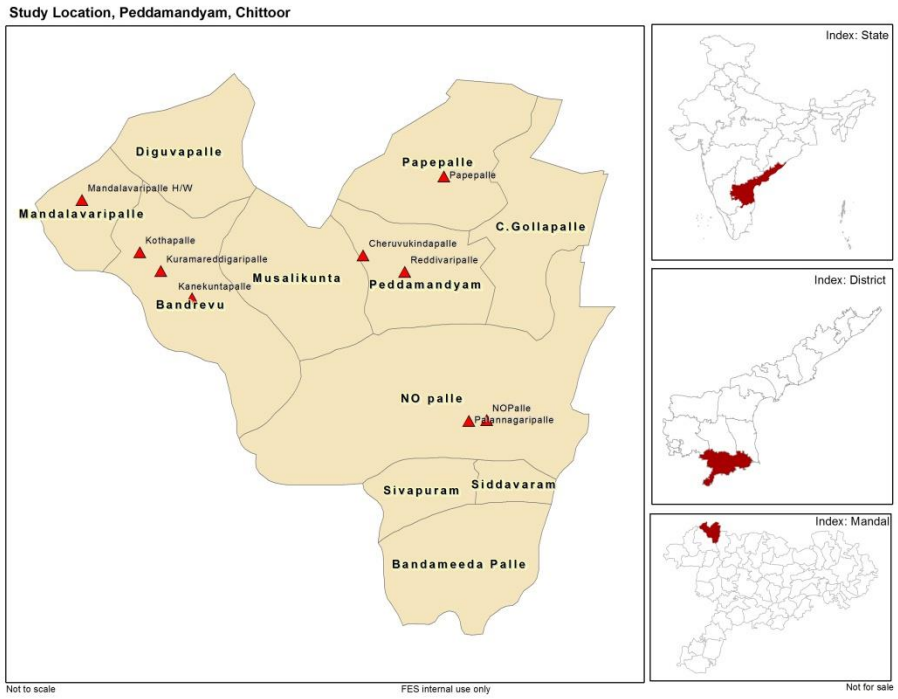
Wang, Y. (2014). Negotiating Access: The Social Process of Liquefied Petroleum Gas (LPG) Cookstove Dissemination Intervention in Himachal Pradesh, India. *Trop Resour Bull*, 32-33.

WHO. (2014a). 7 million premature deaths annually linked to air pollution. Retrieved from http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/

WHO. (2014b). Household air pollution and health. Retrieved from http://www.who.int/mediacentre/factsheets/fs292/en/
WHO. (2014c). *WHO Indoor Air Quality Guidelines: Household Fuel Combustion*. Retrieved from Geneva, Switzerland:
Willis, G. B. (2004). *Cognitive Interviewing: A Tool for Improving Questionnaire Design: A Tool for Improving Questionnaire Design*: Sage Publications.
Woodhouse, D. E., Rothenberg, R. B., Potterat, J. J., Darrow, W. W., Muth, S. Q., Klovdahl, A. S., . . . Muth, J. B. (1994). Mapping a social network of heterosexuals at high risk for HIV infection. *Aids, 8*(9), 1331-1336.
Woolcock, M., & Narayan, D. (2000). Social Capital: Implications for Development Theory, Research, and Policy. *The World Bank Research Observer, 15*(2), 225-249. doi:10.1093/wbro/15.2.225
Xavier, M., Raja, J., & Nandhini, S. U. (2007). Impact of Entrepreneurship Development through Corporate Interventions: An Assessment of the Case of HLL's Project Shakti. *Advances in International Management, 20*, 135-149.
Yadama. (2013a). *Fires, Fuel, and the Fate of 3 Billion : The State of the Energy Impoverished*. Oxford: Oxford University Press, USA.
Yadama. (2013b). *Fires, Fuel, and the Fate of 3 Billion: The State of the Energy Impoverished*: Oxford University Press.
Yadama, Peipert, J., Sahu, M., Biswas, P., & Dyda, V. (2012). Social, Economic, and Resource Predictors of Variability in Household Air Pollution from Cookstove Emissions. *PLoS ONE, 7*(10), e46381. doi:10.1371/journal.pone.0046381
Yamey, G. (2012). What are the barriers to scaling up health interventions in low and middle income countries? A qualitative study of academic leaders in implementation science. *Globalization and Health, 8*(1), 11. doi:10.1186/1744-8603-8-11
Yin, R. K. (2013). *Case study research: Design and methods*: Sage publications.

Appendix 1: Map of study habitations





Appendix 2: Sample size calculation for case-control studies

Sample size per group = $[(\boldsymbol{r}+\mathbf{1}) * \boldsymbol{SD^2} * (\mathbf{Z}_{\beta} + \mathbf{Z}_{\alpha/2})^2]/[\boldsymbol{r} * \boldsymbol{d^2}]$

r = ratio of control to cases. Taken as 1 for matched case-control study design

SD = standard deviation of income data taken from ongoing NIEHS funded R21 RCT on cookstoves in the same mandals, where the study was undertaken. SD=2199.26

Z_{β} = standard normal variate for power. 0.84 for power of 80%

$Z_{\alpha/2}$ = standard normal variate for level of significance. 1.96 for $\alpha = 0.05$

d = expected mean difference in income between case and control groups. d = 545.35

Sample size per group calculated = 255 households

Triangulation of calculation: To triangulate this sample size calculation from the formula, I used Power and Precision 4 software. The criterion for significance (alpha) was set at 0.05. The test was 2-tailed, which means that an effect in either direction will be interpreted. With the proposed sample size of 255 each for case and control group, the study will have power of 80% to yield a statistically significant result. This computation assumes that the mean difference income between the two groups is 545.35 (corresponding to means of 2190.6 versus 1645.0) and the common within-group standard deviation is 2199.26. It is also assumed that this effect size is reasonable, in the sense that an effect of this magnitude could be anticipated in this field of research. On average, a study of this design would enable us to report the mean income difference with a precision of 95% confidence level. For example, an observed difference of 545.0 would be reported with a 95% confidence interval of 162.64 to 927.36. Figure 20 shows the power curve for this study with the total sample size for this matched case-control study design with a control to case ratio of 1. Figure 21 shows the power curve with the sample size per group for this study.

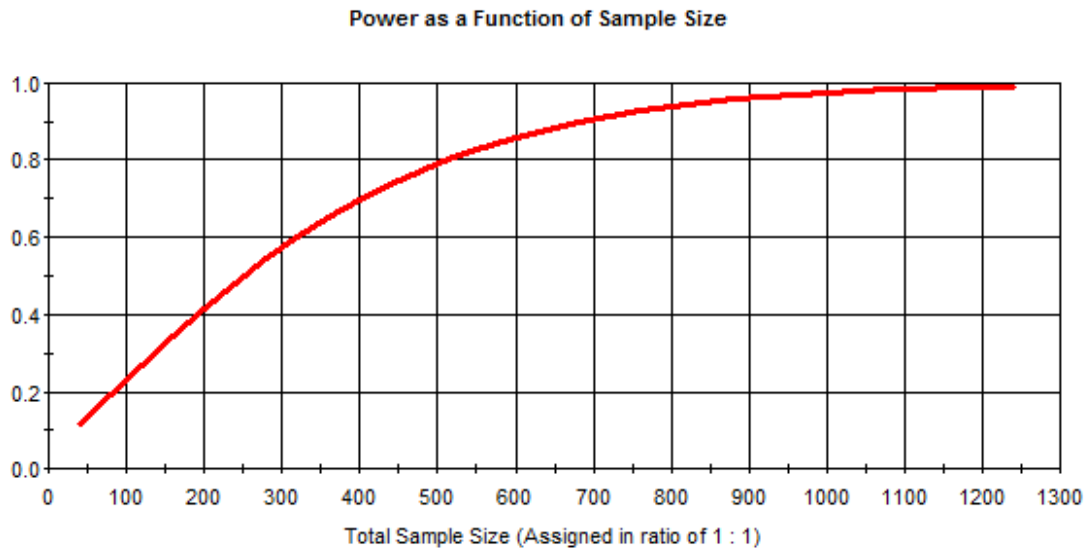


Figure 22: Power curve for total sample size for the study

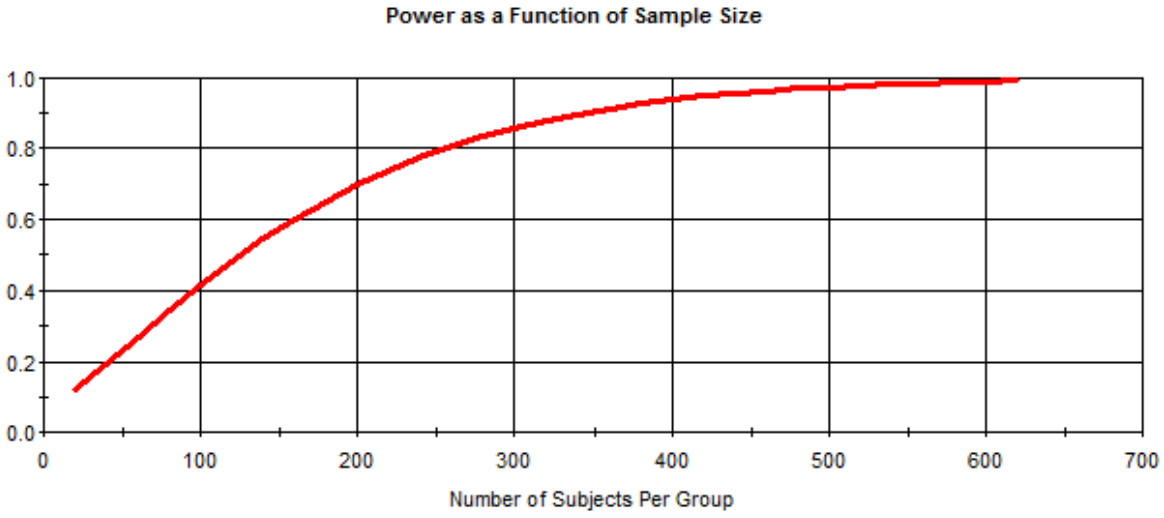


Figure 23: Power curve for sample size per group for the study

Appendix 3: Stratified random sample of habitations

Strata	Proximity to LPG distribution centers	Dominant caste	Absolute frequency of habitations from the habitations population list	Absolute frequency of habitations in the sample (N=35)
1	Nearer	General	30	5
2	Nearer	OBC	23	6
3	Nearer	SC/ST	11	6
4	Far	General	21	5
5	Far	OBC	17	7
6	Far	SC/ST	20	6

Appendix 4: Tables and figures for aim 1 findings

Table 7: Univariate analysis of outcome and predictor variables

Variables	Sample Characteristics (N=510)	Percent of Response
Outcome variable		
LPG Adoption		
Yes	255	50%
No	255	50%
Demographic predictors		
Age		
Mean (SD)	40.34 (13.32)	--
Median (IQR)	38 (19)	--
Marital Status		
Married	445	87.25%
Unmarried	3	0.58%
Widow	62	12.16%
Literacy: Highest level of education completed		
None	336	65.88%
Below or up to class 4	34	6.67%
Class 5 to class 8	69	13.53%
Class 9 to class 10	53	10.39%
Class 11 to class 12	10	1.96%
College	8	1.57%
Literacy: Highest education of male decision maker		
None	223	43.73%
Below or up to class 4	23	4.51%
Class 5 to class 8	120	23.53%
Class 9 to class 10	79	15.49%
Class 11 to class 12	16	3.14%
College	21	4.12%
Not Applicable	28	5.49%
A12 Caste		
General	74	14.51%
OBC	248	48.63%
SC/ST	183	35.88%
Other Religious Minorities	5	0.98%
Others	0	0%
Affordability related predictors		
Income (last month) of the respondent		
Mean (SD)	1056.09 (1005.31)	--
Median (IQR)	1000 (1350)	--

Variables	Sample Characteristics (N=510)	Percent of Response
Membership of SHG		
Yes	341	66.86%
No	169	33.14%
Income (last month) of the household		
Mean (SD)	2912.69 (2270.64)	--
Median (IQR)	2600 (1000)	--
Land ownership of the household		
Mean (SD)	2.15 (3.19)	--
Median (IQR)	2 (2.5)	--
Agricultural debt owed		
Mean (SD)	13,399.41(25789.99)	--
Median (IQR)	0 (20,000)	--
Accessibility related predictors		
Nearest Tarmac road from the household		
Mean (SD)	0.67 (0.98)	--
Median (IQR)	0.4 (0.9)	--
Nearest LPG Distribution center from the household		
Mean (SD)	8.62 (4.73)	--
Median (IQR)	9 (6)	--
Preference for smaller LPG cylinders		
Yes	7	1.37%
No	470	92.16%
Can't say	33	6.47%
Availability of free biomass near the household		
Yes	65	12.75%
No	445	87.25%
Can't say	0	0%
Distance of the biomass source		
Mean (SD)	2.36 (1.37)	--
Median (IQR)	2 (1.5)	--
Decision making capacity to purchase new stove		
Respondent	147	28.82%
Spouse of respondent	236	46.27%
Respondent and spouse of the respondent	103	20.20%

Variables	Sample Characteristics (N=510)	Percent of Response
Respondent, spouse of the respondent, and others	5	0.98%
Respondent and others but not the spouse	10	1.96%
Others but not the respondent or the spouse of the respondent	9	1.76%
Awareness related predictors		
Perception of LPG explosion on adoption		
Yes	45	8.82%
No	465	91.18%
Can't say	0	0%
LPG against household traditional culture		
Yes	6	1.18%
No	489	95.88%
Can't say	15	2.94%
LPG Enhance Social Status		
Yes	501	98.24%
No	9	1.76%
Campaigns Attended		
Yes	40	92.16%
No	470	7.84%

Table 8: Bivariate distribution between LPG adopters and non-LPG adopters

Predictor Variables	LPG adopters (N=255)	Non-LPG adopters (N=255)
Demographic predictors		
Age		
Mean (SD)	38.75 (11.64)	41.92 (14.69)
Median (IQR)	37 (15)	40 (20)
Marital Status		
Married	228 (89.41%)	217 (85.09%)
Unmarried	1 (0.39%)	2 (0.78%)
Widow	26 (10.19%)	36 (14.12%)

Predictor Variables	LPG adopters (N=255)	Non-LPG adopters (N=255)
Literacy: Highest level of education completed		
None	157 (61.57%)	179 (70.20%)
Below or up to class 4	13 (5.09%)	21 (8.23%)
Class 5 to class 8	38 (14.90%)	31 (12.16%)
Class 9 to class 10	36 (14.12%)	17 (6.67%)
Class 11 to class 12	7 (2.75%)	3 (1.18%)
College	4 (1.57%)	4 (1.57%)
Literacy: Highest education of male decision maker		
None		
Below or up to class 4	106 (41.57%)	117 (45.88%)
Class 5 to class 8	8 (3.14%)	15 (5.88%)
Class 9 to class 10	62 (24.31%)	58 (22.74%)
Class 11 to class 12	49 (19.22%)	30 (11.76%)
College	9 (3.53%)	7 (2.74%)
Not Applicable	13 (5.09%)	8 (3.14%)
	8 (3.14%)	20 (7.84%)
Caste		
General	54 (21.17%)	20 (7.84%)
OBC	155 (60.78%)	93 (36.47%)
SC/ST	44 (17.25%)	139 (54.50%)
Other Religious Minorities	2 (0.78%)	3 (1.18%)
Others	0	0
Affordability related predictors		
Income (last month) of the respondent		
Mean (SD)	1200.20 (1023.46)	907.84 (969.17)
Median (IQR)	1100 (1025)	750 (1350)
Membership of SHGs		
No	75 (29.42%)	94 (36.86%)
Yes	180 (70.59%)	161 (63.14%)
Income (last month) of the household		
Mean (SD)	3,473.53 (2,869.99)	2,351.84 (1,218.12)
Median (IQR)	3000 (2000)	2000 (1500)
Land ownership of the household		
Mean (SD)	2.65 (2.95)	1.64 (3.36)
Median (IQR)	2 (3)	1 (2)
Agricultural debt owed by the household		
Mean (SD)	19,179.22 (30,625.10)	7,619.61 (18,160.06)
Median (IQR)	0 (0)	0 (30,000)
Accessibility related predictors		
Nearest Tarmac road from the		

Predictor Variables	LPG adopters (N=255)	Non-LPG adopters (N=255)
household		
Mean (SD)	0.53 (1.13)	0.81 (0.79)
Median (IQR)	0.2 (0.40)	0.5 (1.05)
Nearest LPG distribution center from the household		
Mean (SD)	8.16 (4.90)	9.07 (4.54)
Median (IQR)	7 (7)	9 (6)
Preference for smaller LPG cylinders	2 (0.78%)	5 (1.96%)
Yes	248 (97.25%)	222 (87.05%)
No	5 (1.96%)	28 (10.98%)
Can't say		
Availability of free biomass near the household		
Yes	2 (0.78%)	63 (24.70%)
No	253 (99.21%)	192 (75.29%)
Can't say	0	0
Distance of the biomass source		
Mean (SD)	2.39 (1.57)	2.23 (1.15)
Median (IQR)	2 (1.5)	2 (1.5)
Decision making capacity to purchase new stove		
Respondent	75 (29.41%)	72 (28.23%)
Spouse of respondent	117 (45.88%)	119 (46.66%)
Respondent and spouse of the respondent	48 (18.82%)	55 (21.57%)
Respondent, spouse of the respondent, and others	4 (1.57%)	1 (0.39%)
Respondent and others but not the spouse	6 (2.35%)	4 (1.57%)
Others but not the respondent or the spouse of the respondent	5 (1.96%)	4 (1.57%)
Awareness related predictors		
Perception of LPG explosion on adoption		
Yes	5 (1.96%)	40 (15.69%)
No	250 (98.03%)	215 (84.31%)
Can't say	0	0
LPG against household traditional culture		
Yes	1 (0.39%)	5 (1.96%)
No	242 (94.90%)	247 (96.86%)
Can't say	12 (4.70%)	3 (1.18%)
LPG Enhance Social Status		

Predictor Variables		LPG adopters (N=255)	Non-LPG adopters (N=255)
Campaigns Attended	Yes	253 (99.21%)	248 (97.25%)
	No	2 (0.78%)	7 (2.74%)
	Yes	33 (12.94%)	7 (2.74%)
	No	222 (87.05%)	248 (97.25%)

Table 9: Bivariate analysis between LPG Adoption (outcome variable) and categorical predictors

	chi square[#]	p value
Predictor Variables		
Demographic predictors		
Marital Status	2.21	0.33
Literacy: Highest level of education completed	12.44	0.03
Literacy: Highest education of male decision maker	13.96	0.03
Caste	80.63	<0.001
Affordability related predictors		
Membership of SHGs	2.87	<0.001
Accessibility related predictors		
Preference for smaller LPG cylinders	18.75	<0.001
Availability of free biomass near the household	63.47	<0.001
Decision making capacity to purchase new stove	2.87	0.72
Awareness related predictors		
Perception of LPG explosion on adoption	28.17	<0.001
LPG against household traditional culture	8.12	0.01
LPG Enhance Social Status	1.81	0.18
Campaigns Attended	16.96	<0.001

[#]Chi square test of association was conducted for outcome variable and categorical predicators

Table 10: Bivariate analysis between LPG adopters and non-LPG adopters on continuous predictors

	LPG Adopters vs. non-LPG adopters Mann Whitney U test	p value
Predictor Variables		
Demographic predictors		
Age[#]	-2.69	0.007
Affordability related predictors		
Income (last month) of the respondent	198390	<0.001
Income (last month) of the household	256530	<0.001
Land ownership of the household	140250	0.02
Agricultural debt owed by the household	81090	<0.001
Accessibility related predictors		
Nearest Tarmac road from the household	41692.5	<0.001
Nearest LPG distribution center from the household[#]	-2.17	0.03
Distance of the biomass source	185512	0.71

[#]Welch's T test was conducted for these two continuous predictors.

Table 11: Multicollinearity tests for model 1 - Control Variables

Variables	GVIF	Df
Age	1.73	1
Marital Status	2.09	2
Literacy: Highest education of respondent	1.71	5
Literacy: Highest education of male decision maker	2.49	6
Caste	1.21	3

Table 12: Multicollinearity tests for model 2 - Affordability

Variables	GVIF	Df
Age	1.78	1
Marital Status	2.22	2
Literacy: Highest education of respondent	1.86	5
Literacy: Highest education of male decision maker	2.77	6
Caste	1.30	3
Income (last month) of the respondent	1.15	1
Membership of SHGs	1.09	1
Income (last month) of the household	1.22	1
Land ownership of the household	1.12	1
	1.13	1

Table 13: Multicollinearity tests for model 3 - Accessibility

Variables	GVIF	Df
Age	1.80	1
Marital Status	2.72	2
Literacy: Highest education of respondent	1.97	5
Literacy: Highest education of male decision maker	3.02	6
Caste	1.42	3
Nearest Tarmac road from the household	1.17	1
Nearest LPG distribution center from the household	1.11	1
Preference for smaller LPG cylinders	1.13	1
Availability of free biomass near the household	1.04	1
Distance of the biomass source	1.12	1
Decision making capacity to purchase new stove	1.93	5

Table 14: Multicollinearity tests for model 4 - Awareness

Variables	GVIF	Df
Age	1.73	1
Marital Status	2.09	2
Literacy: Highest education of respondent	1.71	5
Literacy: Highest education of male decision maker	2.49	6
Caste	1.21	3
Perception of LPG explosion on adoption	1.07	1
LPG against household traditional culture	1.13	2
LPG Enhance Social Status	1.05	1
Campaigns Attended	1.07	1

Table 15: Multicollinearity tests for model 5 - Affordability + Accessibility + Awareness (3As)

Variables	GVIF	Df
Age	1.92	1
Marital Status	2.67	2
Literacy: Highest education of respondent	2.33	5
Literacy: Highest education of male decision maker	3.85	6
Caste	1.72	3
Income (last month) of the respondent	1.29	1
Membership of SHGs	1.18	1
Income (last month) of the household	1.22	1
Land ownership of the household	1.25	1
Income (last month) of the respondent	1.20	1
Nearest Tarmac road from the household	1.33	1
Nearest LPG distribution center from the household	1.15	1
Preference for smaller LPG cylinders	1.21	1
Availability of free biomass near the household	1.32	1
Distance of the biomass source	1.17	1
Decision making capacity to purchase new stove	2.34	5
Perception of LPG explosion on adoption	1.18	1
LPG against household traditional culture	1.13	2
LPG Enhance Social Status	1.04	1
Campaigns Attended	1.22	1

Table 16: Hosmer-Lemeshow Goodness of Fit Statistic for Each Model

Regression models	chi-squared	p values	Df
Model 1	6.40	0.60	8
Model 2	10.45	0.23	8
Model 3	15.06	0.06	8
Model 4	7.41	0.49	8
Model 5	9.85	0.28	8

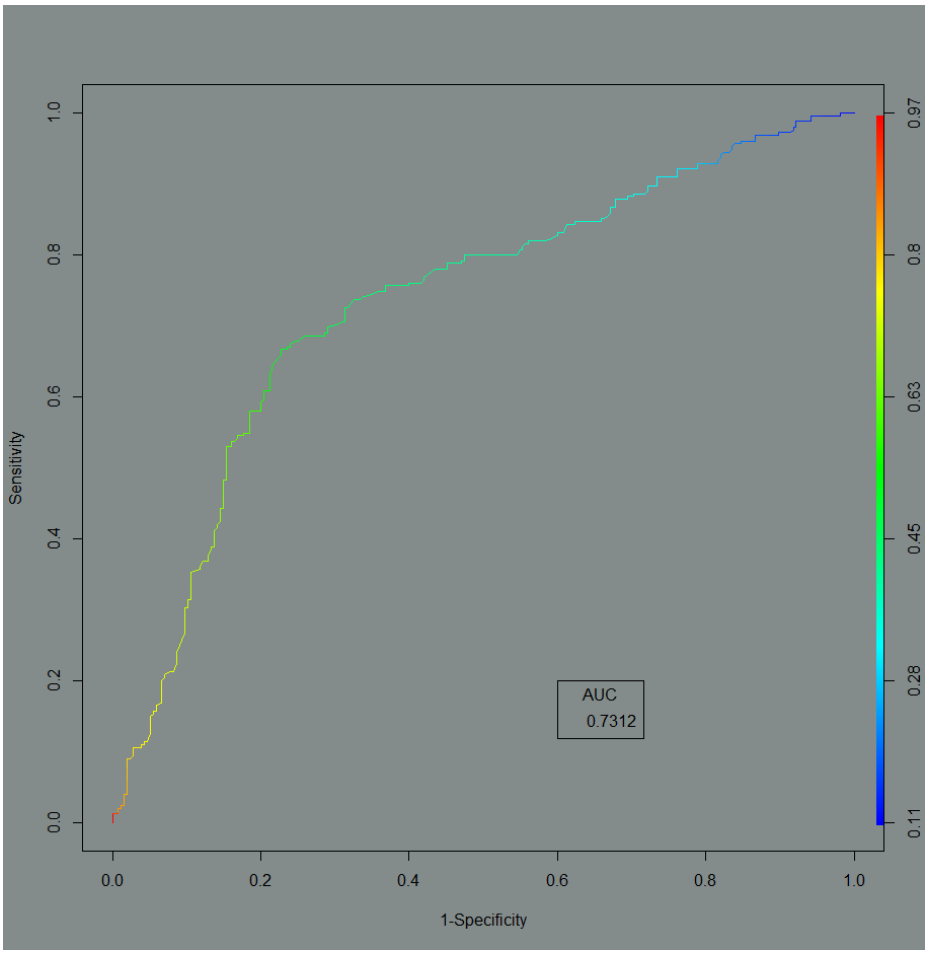


Figure 24: ROC curve for model 1 (demographic)

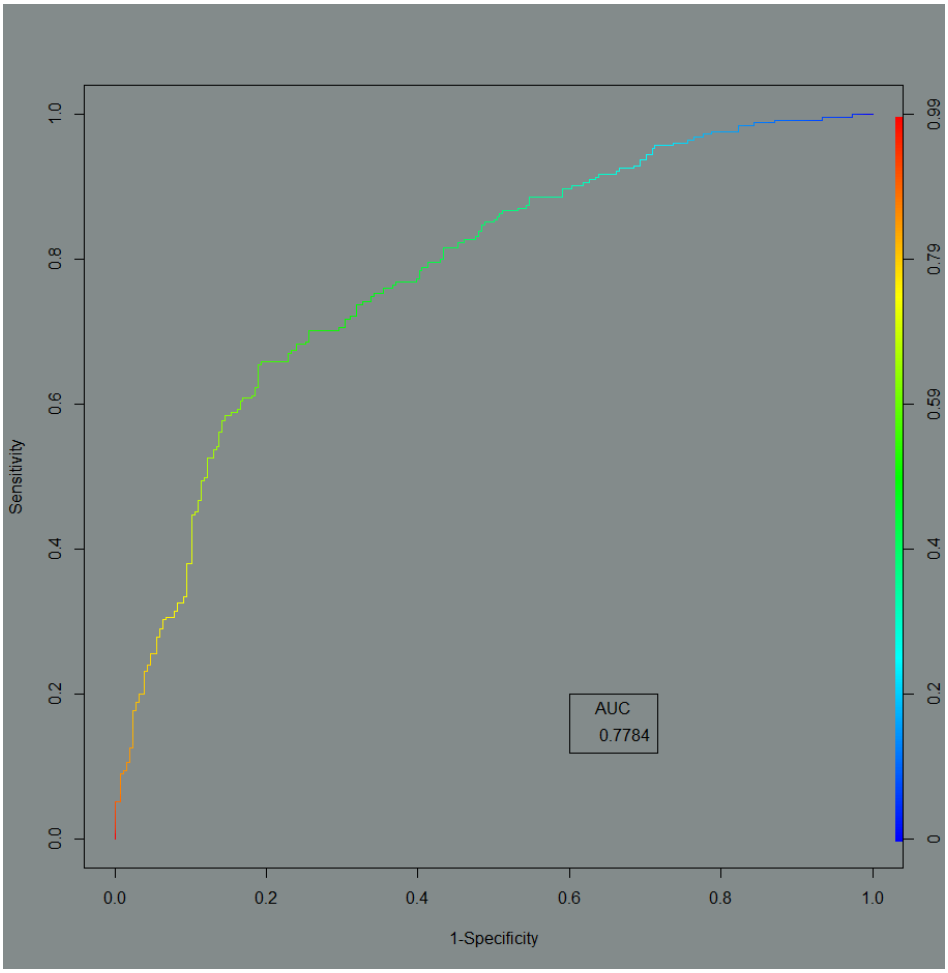


Figure 25: ROC curve for model 2 (affordability)

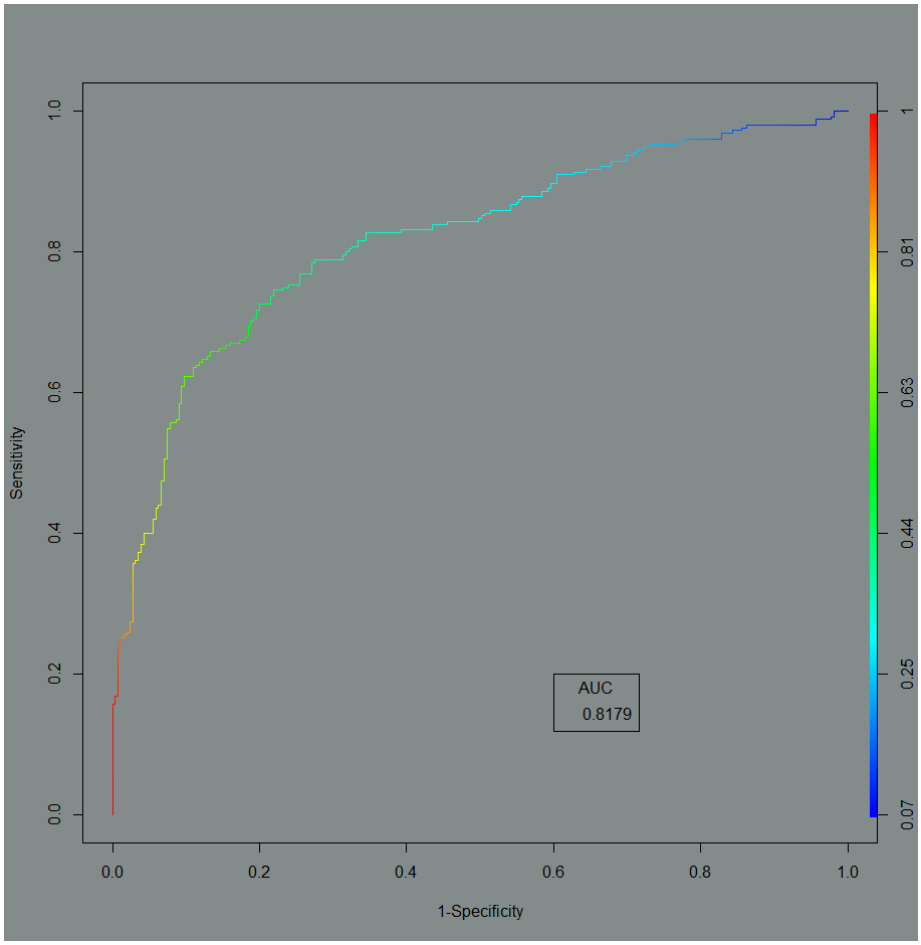


Figure 26: ROC curve for model 3 (accessibility)

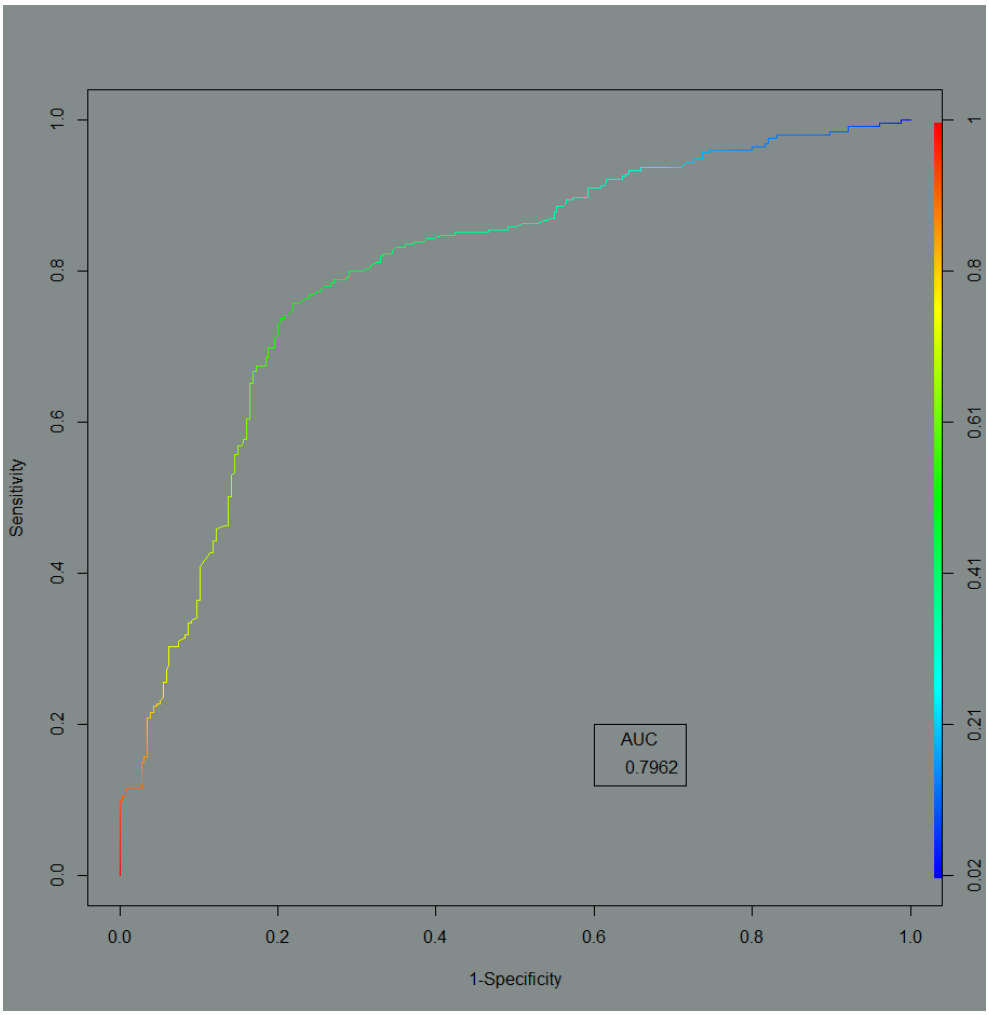


Figure 27: ROC curve for model 4 (awareness)

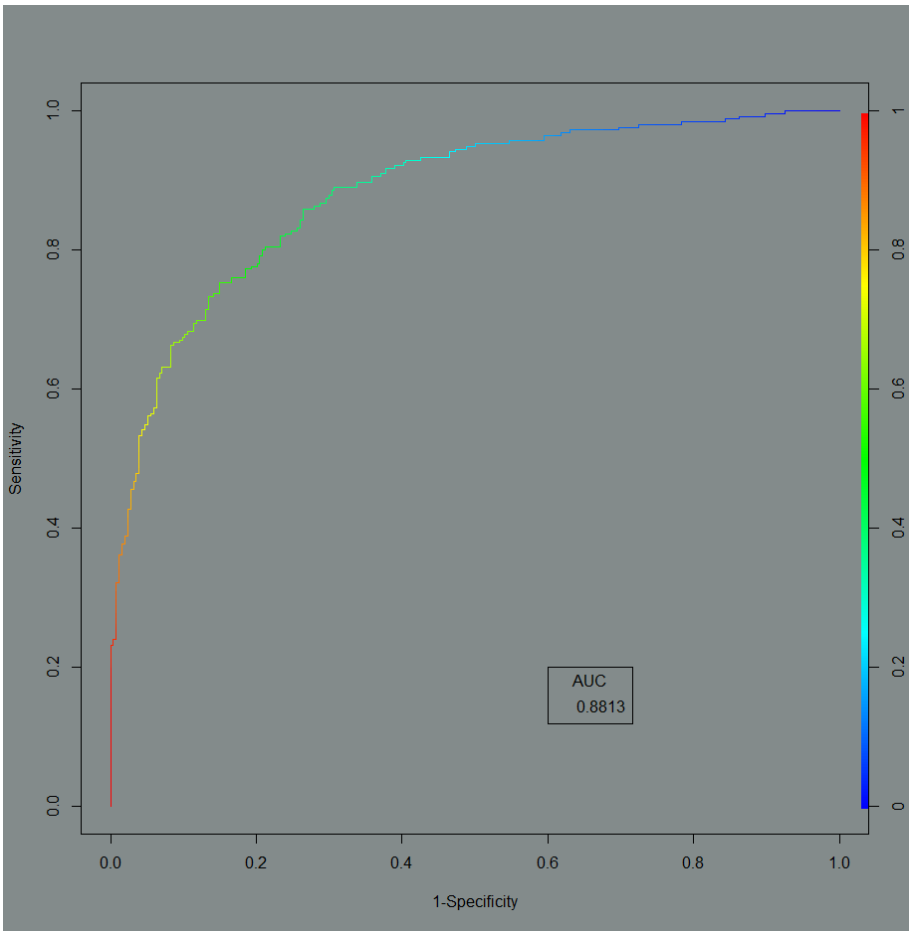


Figure 28: ROC curve for model 5 (3As)

Table 17: Binomial logistic regression analyses with outcome variable: adoption of LPG by households

	Model 1 (Demographic)		Model 2 (Affordability)		Model 3 (Accessibility)		Model 4 (Awareness)		Model 5 (3As)	
	OR (95% CI)	**p value**	**OR (95% CI)**	**p value**	**OR (95% CI)**	**p value**	**OR (95% CI)**	**p value**	**OR (95% CI)**	**p value**
Demographic predictors										
Age (years)	**0.97 (0.95-0.99)**	**0.01****	0.98 (0.96-1.00)	0.06	0.99 (0.97-1.01)	0.33	**0.97 (0.95-0.99)**	**<0.01****	0.99 (0.97-1.02)	0.62
Marital status										
Married	2.02 (0.14-54.13)	0.61	4.34 (0.16-207.72)	0.44	2.29 (0.13-70.50)	0.58	5.24 (0.22-245.92)	0.37	44.69 (0.36-9853.9)	0.25
Divorced (Reference: unmarried)	2.65 (0.16-78.16)	0.50	10.15 (0.33-549.44)	0.24	1.60 (0.08-57.00)	0.75	8.81 (0.32-466.37)	0.25	45.34 (0.32-1121.8)	0.26
Literacy: Highest education of the respondent										
Below or up to class 4:	0.70 (0.30-1.58)	0.40	0.68 (0.28-1.63)	0.40	0.59 (0.24-1.44)	0.26	0.78 (0.31-1.90)	0.58	0.55 (0.19-1.57)	0.27
Class 5 to class 8:	0.81 (0.43-1.51)	0.51	0.90 (0.47-1.71)	0.74	0.82 (0.31-1.64)	0.53	0.68 (0.35-1.32)	0.25	0.89 (0.40-1.99)	0.78
Class 9 to class10:	1.35 (0.64-2.92)	0.41	1.41 (0.65-3.14)	0.39	1.39 (0.63-3.16)	0.41	0.94 (0.42-2.14)	0.88	1.35 (0.53-3.50)	0.52
Class 11 to class 12:	1.84 (0.40-10.12)	0.44	1.16 (0.21-7.74)	0.87	3.15 (0.53-25.15)	0.23	2.02 (0.38-12.55)	0.42	3.24 (0.41-29.21)	0.27
College: (Reference: No education)	0.96 (0.17-5.1)	0.96	1.28 (0.18-7.93)	0.79	1.07 (0.54-2.16)	0.94	1.22 (0.17-8.76)	0.84	2.67 (0.24-28.47)	0.40
Literacy: Highest education of male decision maker										
Below or up to class 4:	0.42 (0.15-1.12)	0.09	**0.33 (0.11-0.93)**	**0.04***	0.33 (0.11-0.97)	0.05	**0.27 (0.09-0.78)**	**0.02***	**0.19 (0.05-0.71)**	**0.02***
Class 5 to class 8:	0.84 (0.50-1.38)	0.49	0.69 (0.40-1.17)	0.17	0.74 (0.42-1.30)	0.29	0.58 (0.33-1.00)	0.05	**0.4 (0.20-0.77)**	**<0.01****
Class 9 to class10:	1.23 (0.66-2.31)	0.52	1.02 (0.53-1.98)	0.95	1.07 (0.54-2.16)	0.83	1.24 (0.64-2.44)	0.52	1.09 (0.50-2.40)	0.82
Class 11 to class 12:	0.90 (0.28-3.05	0.86	0.76 (0.20-2.88)	0.68	0.89 (0.27-3.16)	0.91	0.87 (0.25-3.18)	0.82	0.65 (0.16-2.87)	0.56
College:	0.96 (0.33-2.89)	0.94	0.46 (0.13-1.62)	0.22	0.92 (0.28-3.24)	0.90	0.69 (0.21-2.40)	0.56	0.27 (0.56-1.35)	0.10
Not Applicable: (Reference: No education)	0.40 (0.12-1.30)	0.14	0.34 (0.10-1.18)	0.10	0.55 (0.14-2.10)	0.36	0.26 (0.07-0.91)	0.05	0.51 (0.11-2.31)	0.39
Caste										
OBC	0.64 (0.34-1.15)	0.14	0.74 (0.38-1.38)	0.35	0.49 (0.23-0.98)	0.05	0.70 (0.36-1.33)	0.29	0.68 (0.29-1.49)	0.34
SC/ST	**0.11 (0.05-0.20)**	**<0.001*****	**0.13 (0.06-0.27)**	**<0.001*****	**0.08 (0.04-0.18)**	**<0.001*****	**0.09 (0.04-0.18)**	**<0.001*****	**0.11 (0.04-0.2)**	**<0.001**
Other religious minorities (Reference: General)	0.47 (0.05-3.55)	0.46	0.40 (0.03-4.40)	0.45	0.26 (0.03-2.23)	0.20	0.46 (0.05-3.63)	0.45	0.36 (0.02-4.36)	0.42
Affordability related predictors										
Income (last month) of the respondent										
INR			**1.0002 (1.00009-**	**0.04***					**1.0006 (1.0003-**	**<0.001*****

	Model 1 (Demographic)		Model 2 (Affordability)		Model 3 (Accessibility)		Model 4 (Awareness)		Model 5 (3As)	
	OR (95% CI)	p value	OR (95% CI)	p value	OR (95% CI)	p value	OR (95% CI)	p value	OR (95% CI)	p value
			1.0004)						**1.0009)**	
Membership with SHG *Yes* *(Reference: No)*			**1.81 (1.16-2.86)**	**<0.01****					1.48 (0.48-2.62)	0.16
Income (last month) of the household *INR*			**1.0003 (1.0001-1.0004)**	**<0.001*****					**1.0002 (1.00003-1.0004)**	**0.03***
Land ownership of the household *INR*			1.03 (0.97-1.13)	0.40					1.06 (0.97-1.15)	0.15
Agricultural debt owed by the household *INR*			**1.00001 (1.000002-1.000003)**	**0.01***					**1.00 (1.00-1.00)**	**0.001****
Accessibility related predictors										
Nearest Tarmac from the household *Kms*					**0.73 (0.54-0.89)**	**0.03***			**0.74 (0.57-0.96)**	**0.02***
Nearest LPG distribution center from the household *Kms*					0.98 (0.94-1.03)	0.48			0.96 (0.90-1.01)	0.13
Preference for Smaller LPG cylinders *No* *Can't say* *(Reference: Yes)*					0.90 (0.07-12.49) 0.15 (0.01-2.66)	0.93 0.18			4.11 (0.19-72.02) 0.62 (0.02-14.70)	0.33 0.77
Availability of free biomass near the household *Yes* *(Reference: No)*					**0.02 (0.003-0.007)**	**<0.001*****			**0.01 (7e-4-3.3e-02)**	**<0.001*****
Distance of the biomass source *Kms*					**1.18 (1.01-1.39)**	**0.04***			**1.20 (1.00-1.44)**	**0.03***
Decision making capacity to purchase new stove *Spouse of respondent* *Respondent and spouse of the respondent* *Respondent, spouse of the respondent, and others* *Respondent and others but not the spouse* *Others but not the respondent or the spouse of the respondent* *(Reference: Respondent)*					0.62 (0.33-1.12) 0.78 (0.38-1.59) 1.19 (0.15-25.36) 0.86 (0.16-5.99) 0.93 (0.16-6.31)	0.12 0.49 0.88 0.86 0.94			0.53 (0.26-1.05) 0.60 (0.26-1.36) 1.29 (0.16-27.48) 2.77 (0.42-21.03) 1.45 (0.16-2.74)	0.07 0.21 0.83 0.29 0.75

	Model 1 (Demographic)		Model 2 (Affordability)		Model 3 (Accessibility)		Model 4 (Awareness)		Model 5 (3As)	
	OR (95% CI)	**p value**	**OR (95% CI)**	**p value**	**OR (95% CI)**	**p value**	**OR (95% CI)**	**p value**	**OR (95% CI)**	**p value**
Awareness related predictors										
Perception of LPG explosion on adoption										
Yes							**0.07 (0.02-0.17)**	**<0.001*** **	**0.11 (0.03-0.3)**	**<0.001*** **
(Reference: No)										
LPG against household traditional culture										
Yes							**0.09 (0.004-0.72)**	**0.04***	0.10 (0.004-9.77e-01)	0.06
Can't Say							2.83 (0.77-13.95)	0.15	4.37 (0.72-56.85)	0.18
(Reference: No)										
LPG Enhances social status										
Yes							**7.02 (1.14-60.84)**	**0.04***	2.21 (0.11-43.09)	0.57
(Reference: No)										
Campaigns attended										
Yes							**6.23 (2.49-17.75)**	**<0.001*** **	**17.51 (4.09-122.25)**	**<0.001*** **
(Reference: No)										
AIC	635.64		599.19		565.26		575.26		484.42	
McFadden's R square	0.15		0.22		0.28		0.25		0.43	

*****p<0.001; **p<0.01; *p<0.05**

Ref: Non-adoption of LPG

Appendix 5: Tables and figures for aim 2 findings

Table 18: Structural characteristics of personal network data of LPG women, non-LPG women, LPG men, and non-LPG men

	Mean	Median	Standard deviation (SD)	Interquartile range (IQR)
LPG women (N=100)				
Network size	5.96	6.00	2.23	2
Network density	0.97	1.00	0.05	0.02
Effective size	1.35	1.00	0.63	0.48
Non-LPG women (N=97)				
Network size	6.31	7.00	1.18	2
Network density	0.96	1.00	0.14	0
Effective size	1.30	1.00	1.11	0
LPG men (N=82)				
Network size	6.06	6.00	1.44	2
Network density	0.98	1.00	0.07	0
Effective size	1.29	1.00	0.61	0.2
Non-LPG men (N=82)				
Network size	6.25	7.00	0.98	2
Network density	0.97	1.00	0.14	0
Effective size	1.11	0.80	0.40	0

Table 19: Normality assumptions for structural analyses of personal network data of LPG women, non-LPG women, LPG men, and non-LPG men

	Shapiro Wilk's test	Skewness	Kurtosis
LPG women			
Network size	0.79***	2.63	14.98
Network density	0.55***	-2.49	6.13
Effective size	0.63***	1.87	5.44
Non-LPG women			
Network size	0.80***	-0.90	1.82
Network density	0.24***	-4.94	23.84
Effective size	0.78***	3.95	5.11
LPG men			
Network size	0.90***	-0.008	-0.18
Network density	0.32**	-3.98	16.39
Effective size	0.74***	2.65	5.12
Non-LPG men			
Network size	0.75***	-0.46	-1.33
Network density	0.23**	-4.54	19.92
Effective size	0.86***	3.66	5.03

*****p<0.001; **p<0.01; *p<0.05**

Table 20: Bivariate analyses for structural characteristics of personal network data of LPG women, non-LPG women, LPG men, and non-LPG men

	Welch's T-test	P value
LPG women and non-LPG women		
Network size	-0.73	0.46
Network density[#]	2755	<0.01
Effective size	0.34	0.73
LPG men and non-LPG men		
Network size	-1.01	0.31
Network density[#]	3329	0.82
Effective size	2.02	0.04

[#]Mann Whitney U test

Table 21: Compositional characteristics of personal network data of LPG women, non-LPG women, LPG men, and non-LPG men

	Mean	Median	Standard deviation (SD)	Interquartile range (IQR)
LPG women (N=100)				
E-I gender index	-0.35	-0.47	0.51	0.71
E-I caste index	-0.80	-1.00	0.47	0
E-I LPG adoption status index	-0.55	-0.65	0.46	0.79
Non-LPG women (N=97)				
E-I gender index	-0.19	-0.07	0.52	0.81
E-I caste index	-0.81	-1.00	0.47	0
E-I LPG adoption status index	0.03	0.14	0.56	0.86
LPG men (N=82)				
E-I gender index	-0.65	-1.00	0.42	0.67
E-I caste index	-0.66	-1.00	0.53	0.49
E-I LPG adoption status index	-0.58	-0.71	0.47	0.75
Non-LPG men (N=82)				
E-I gender index	-0.40	-0.60	0.47	0.68
E-I caste index	-0.65	-1.00	0.63	0.32
E-I LPG adoption status index	-0.15	-0.14	0.50	0.80

Table 22: Normality assumptions for compositional analyses of personal network data of LPG women, non-LPG women, LPG men, and non-LPG men

	Shapiro-Wilk's test	Skewness	Kurtosis
LPG women (N=100)			
E-I gender index	0.92***	0.48	2.72
E-I caste index	0.48***	2.65	9.51
E-I LPG adoption status index	0.86***	0.74	2.50
Non-LPG women (N=97)			
E-I gender index	0.92***	-0.15	1.79
E-I caste index	0.49***	2.68	9.49
E-I LPG adoption status index	0.96***	-0.18	2.06
LPG men (N=82)			
E-I gender index	0.79***	0.88	2.53
E-I caste index	0.69*	1.52	4.32
E-I LPG adoption status index	0.84***	0.89	2.75
Non-LPG men (N=82)			
E-I gender index	0.92***	0.37	2.35
E-I caste index	0.60**	1.60	4.07
E-I LPG adoption status index	0.96***	-0.07	2.21

*****p<0.001; **p<0.01; *p<0.05**

Table 23: Bivariate analyses of compositional characteristics for personal network data of LPG women, non-LPG women, LPG men, and non-LPG men

	Welch's Two Sample T test	P value
LPG women and non-LPG women		
E-I gender index	-2.00	0.04
E-I caste index[#]	3312	0.81
E-I LPG adoption status index	-7.29	<0.001
LPG men and non-LPG men		
E-I gender index	-3.72	<0.001
E-I caste index[#]	3582	0.39
E-I LPG adoption status index	-5.52	<0.001

[#]Mann Whitney U test

Appendix 6: LPG study eligibility questionnaire

RedCap ID	_____
Form version	_____
Initials of person doing entry	_____
Tester initials	_____
E1 Date of interview-day	_____
E1 Date of interview-month	_____
E1 Date of interview-year	_____

Following questions are for the woman (primary cook) of the household. She is the primary respondent for this study.	
E2 Taluka ID	◯ 1- Peddamandyam ◯ 2- Thambalpalle
E3 Hamlet ID	_____
E4 Household ID	_____
E5 Has the respondent signed the informed consent? If 'No' STOP here, and proceed to the next household.	◯ 1- Yes ◯ 2- No
E6 Has an adult male (senior most or primary household decision maker) signed the informed consent? If 'No' STOP here and proceed to the next household	◯ 1- Yes ◯ 2- No
E7 Does this household have a BPL card?	◯ 1- yes ◯ 2- no
E8 Are you the primary cook of the household?	◯ 1- Yes ◯ 2- No
E9 Have you been residing in this household for the last 12 months?	◯ 1- Yes ◯ 2- No
E10 Will you reside in this household at least for 12 months from now?	◯ 1- Yes ◯ 2- No
Following questions is for the spouse of the primary respondent/senior most male member/primary male decision maker of the household.	
E11 Has an adult male (senior most or primary household decision maker) signed the informed consent? If 'No' STOP here and proceed to the next household	◯ 1- Yes ◯ 2- No
If answers to E5-E11 were YES, then proceed below. If anyone of the answers in E5-E11 was NO, STOP here, and proceed to the next household.	
E12 Does the household have an LPG cylinder and stove?	◯ 1- Yes ◯ 2- No
E13 If E12=YES, did the household receive the first LPG connection within the past 12 months? Enumerators should check the connection card for the first LPG connection to validate.	◯ 1- Yes ◯ 2- No

• **If answers to E12 and E13 were YES, <u>enroll the household in the case group</u>: LPG adopter households (group 1).** • **If answer to E12 was NO, <u>enroll the household in the control group</u>: non-LPG adopter households (group 2).** • **If the answer to E12 was YES and answer to E13 was NO; STOP here, and proceed to the next household.**	
E14 Does this household belong to case group: LPG adopter households (group 1)	◯ 1- Yes ◯ 2- No
E15 If E14=YES, has this household agreed for SUMS use in the consent form?	◯ 1- Yes ◯ 2- No
If E15=YES, this household is eligible for SUMS use. We will randomly select 100 households to install SUMS from all such eligible LPG adopter households, who consent for SUMS use.	

Appendix 7: LPG adoption questionnaire

RedCap ID	_____
Form version	_____
Initials of person doing entry	_____
Tester initials	_____
A1 Date of interview-day	_____
A1 Date of interview-month	_____
A1 Date of interview-year	_____
A2 Mandal ID	◯ 1- Peddamandyam ◯ 2- Thambalpalle
A3 Habitation ID	_____
A4 Household ID	_____
All the above information will automatically populate in RedCap system.	

Woman (primary cook of the household) will be the respondent of this questionnaire.

A5 Which group does this household belong to?	◯ 1- LPG adopter household (group 1) ◯ 2- non-LPG adopter household (group 2)
Following questions pertain to the basic household background.	
A6 What is your age in years? Enumerators should verify from documented records	_____
A7 Which record was used to verify age?	◯ 1- birth certificate ◯ 2- ASHA record ◯ 3- ration card ◯ 4- independent household recording of birth ◯ 5-self-report ◯ 6-Aadhar card

A8 Marital status	◯ 1- married ◯ 2- unmarried ◯ 3- Widow ◯ 4- divorced .
A9 If A8=1, 3, or 4; number of children the respondent has	◯ 0 ◯ 1 ◯ 2 ◯ 3 ◯ 4 or more
A10 What is the highest level of education you have completed?	◯ 1- none ◯ 2- below or up to class 4 ◯ 3- class 5 to class 8 ◯ 4- class 9 to class 10 ◯ 5- class 11 to class 12 ◯ 6- college
A11 What is the highest level of education of the primary male decision maker of the household?	◯ 1- none ◯ 2- below or up to class 4 ◯ 3- class 5 to class 8 ◯ 4- class 9 to class 10 ◯ 5- class 11 to class 12 ◯ 6- college
A12 Caste of the respondent	◯ 1- general ◯ 2- OBC ◯ 3- SC/ST ◯ 4- Other religious minorities ◯ 5- others

Stove adoption

Following questions pertain to your choice of adoption of different types of cooking stoves. Note: Although asked to the woman respondent, the questions pertain to the entire household unless otherwise specifically mentioned

A13 What type of stoves do you currently have in your household? Check all that apply

- ◯ 1- LPG
- ◯ 2- traditional stoves
- ◯ 3- kerosene stoves
- ◯ 4- improved biomass stoves
- ◯ 5- Electric induction stoves

A14 What type of stoves have you normally used for cooking in the last 1 year? Check all that apply.

- ◯ 1- LPG
- ◯ 2- traditional stoves
- ◯ 3- kerosene stoves
- ◯ 4- improved biomass stoves
- ◯ 5- Electric induction stoves

A15 How many traditional stoves do you have? _____

A16 Where do you normally cook?

- ◯ 1- outside the house in an open space
- ◯ 2- inside the house in a kitchen
- ◯ 3- inside the house but not in kitchen

A17 Estimate the number of hours of cooking you do every day _____

Determinants of LPG adoption: affordability

Following questions pertain to your and your households' affordability. These factors might have impacted your choice on LPG adoption.

Women's autonomy

A18 Do you have employment outside your house?

- ◯ 1- yes
- ◯ 2- no

A19 If A18 = 1, how much did you earn last month from your employment outside your house _____

A20 If A18 = 1, who decides for the expenditure of the money you earned?

- ◯ 1- respondent
- ◯ 2- spouse of the respondent
- ◯ 3- respondent and spouse of the respondent
- ◯ 4- Respondent, spouse of the respondent, and others
- ◯ 5- respondent and other but not the spouse
- ◯ 6- others but not the respondent or the spouse of the respondent

Now, we will ask you questions on how do you make decisions on some of the key household related issues:

A21 If you have to leave or left this job, who would/did influence your decision?
?

- ◯ 1- respondent
- ◯ 2- spouse of the respondent
- ◯ 3- respondent and spouse of the respondent
- ◯ 4- Respondent, spouse of the respondent, and others
- ◯ 5- respondent and other but not the spouse
- ◯ 6- others but not the respondent or the spouse of the respondent

A22 If the house has to buy land, who would/does usually decide?

- ◯ 1- respondent
- ◯ 2- spouse of the respondent
- ◯ 3- respondent and spouse of the respondent
- ◯ 4- Respondent, spouse of the respondent, and others
- ◯ 5- respondent and other but not the spouse
- ◯ 6- others but not the respondent or the spouse of the respondent
- ◯ 7- Household does not have any land holdings

A23 If the house has land holdings, who has the ownership in the legal deed?

- ◯ 1- respondent
- ◯ 2- spouse of the respondent
- ◯ 3- respondent and spouse of the respondent
- ◯ 4- Respondent, spouse of the respondent, and others
- ◯ 5- respondent and other but not the spouse
- ◯ 6- others but not the respondent or the spouse of the respondent
- ◯ 7- Household does not have any land holdings

A24 If you need a new stove, who would/does usually decide?

- ◯ 1- respondent
- ◯ 2- spouse of the respondent
- ◯ 3- respondent and spouse of the respondent
- ◯ 4- Respondent, spouse of the respondent, and others

◯ 5- respondent and other but not the spouse
◯ 6- others but not the respondent or the spouse of the respondent

A25 If you need new utensils, who would/does usually decide?

◯ 1- respondent
◯ 2- spouse of the respondent
◯ 3- respondent and spouse of the respondent
◯ 4- Respondent, spouse of the respondent, and others
◯ 5- respondent and other but not the spouse
◯ 6- others but not the respondent or the spouse of the respondent

A26 If you have to repair your stove, who would/does usually decide?

◯ 1-respondent
◯ 2-spouse of the respondent
◯ 3-respondent and spouse of the respondent
◯ 4-Respondent, spouse of the respondent, and others
◯ 5-respondent and other but not the spouse
◯ 6-others but not the respondent or the spouse of the respondent

A27 If you have to step out of house, who would/does decide?

◯ 1- respondent
◯ 2- spouse of the respondent
◯ 3- respondent and spouse of the respondent
◯ 4- Respondent, spouse of the respondent, and others
◯ 5- respondent and other but not the spouse
◯ 6- others but not the respondent or the spouse of the respondent

A28 Are you a member of any self-help group?

◯ 1- yes
◯ 2- no

A29 What is your current occupation? Check all that apply

◯ 1- home maker
◯ 2- self-employed: farm
◯ 3- self-employed: non-farm
◯ 4- agricultural labor
◯ 5- Non-agricultural labor
◯ 6- other

Economic status of household
Note: Although asked to the woman respondent, the questions pertain to the entire household unless otherwise specifically mentioned.

A30 What has been the average income of this household last month? _____

A31 How has been the regularity of the average household income in the last 1 year?
- ◯ 1- regular across all seasons
- ◯ 2- fluctuated with seasons

A32 What is the current occupation of the head of the household? (check all that apply)
- ◯ 1- home maker
- ◯ 2- self-employed: farm
- ◯ 3- self-employed: non-farm
- ◯ 4- agricultural labor
- ◯ 5- non-agricultural labor
- ◯ 6- other

A33 How much land does the household currently own in acres? _____

A34 Ownership status of the household
- ◯ 1- own
- ◯ 2- rented

A35 Type of household
- ◯ 1- kuccha
- ◯ 2- semi- pukka
- ◯ 3- pukka

A36 What is the amount of agricultural debt do you currently owe? _____

A37 What is the amount of non-agricultural debt do you currently owe? _____

A38 Is this village connected to grid based electricity?
- ◯ 1- yes
- ◯ 2- no

A39 What is the primary source of lighting in your household?
- ◯ 1- grid based electricity
- ◯ 2- off-grid like solar
- ◯ 3- traditional means of lighting (such as kerosene lamp)

A40 Has this village been impacted by a drought or famine in the last 1 year?
- ◯ 1- yes
- ◯ 2- no

Determinants of LPG adoption: accessibility

Following questions pertain to your households' accessibility which might have influenced your decision on LPG adoption.

Note: Although asked to the woman respondent, the questions pertain to the entire household unless otherwise specifically mentioned.

A41 Is a tarmac road available in the village?	◯ 1- yes ◯ 2- No
A42 What is the distance (in km) of the nearest tarmac road from this village?	_____
A43 What is the distance (in km) of the nearest LPG distribution center from this village? (Enumerators should be aware of the nearest LPG distribution center and its distance from this region)	_____
A44 What is the distance (in km) of the nearest LPG stove repair center from this village? (Enumerators should be aware of the nearest LPG repair center and its distance from this region)	_____
A45 How did your household apply for LPG connection?	◯ 1- never applied ◯ 2- through self ◯ 3- through government official ◯ 4- through SHGs ◯ 5- through other means not involving govt./SHGs
A46 If you applied for LPG connection in last 12 months, what is the current status?	◯ 1- applied but waiting for connection ◯ 2- received connection
Now, we will ask you questions on accessibility related issues which might have influenced your decision on adoption of LPG.	
A47 Self delivery of LPG cylinders deter adoption of LPG	◯ 1 yes ◯ 2 no ◯ 3 Can't say
A48 Smaller LPG cylinders (5 Kg) are better than 14.5 Kg cylinders to adopt	◯ 1- yes ◯ 2- no ◯ Can't say
A49 SHGs as rural distribution channels motivate adoption of LPG	◯ 1. yes ◯ 2. no ◯ 3. Can't say
A50 For an LPG connection, loans are available to me	◯ 1- yes ◯ 2- no ◯ 3- Can't say
A51 Payment of upfront cost by the government motivate LPG adoption	◯ 1- yes ◯ 2- no

	◯ 3- Can't say
A52 Access to government subsidies motivate LPG adoption	◯ 1- yes ◯ no ◯ Can't say
A53 Free availability of biomass deter adoption of LPG	◯ 1- yes ◯ 2- no ◯ 3- Can't say
A54 High cost of refilling LPG cylinder deter adoption of LPG	◯ 1 yes ◯ 2 no ◯ 3 Can't say
A55 Longer time taken to refill LPG cylinder deter adoption of LPG	◯ 1 yes ◯ 2 no ◯ 3 Can't say
A56 Longer distance of the LPG distribution center deter adoption of LPG	◯ 1 yes ◯ 2 no ◯ 3 Can't say
A57 Facility of payment in installments motivate adoption of LPG	◯ 1 yes ◯ 2 no ◯ 3 Can't say

Determinants of LPG adoption: awareness

Following questions will ascertain your general awareness level on LPG and LPG adoption.

Agency	Attended campaigns/promotions on LPG in last 1 year:	number of such campaigns/promotions attended in last 1 year
State government	A58 ◯ 1- yes ◯ 2- No	A59 _____
SHGs	A60 ◯ 1- yes	A61 _____

	◯ 2- no	
A75 NGOs	A62 ◯ 1- yes ◯ 2- no	A63 _____
A76 Oil marketing companies or dealers from BPCL, HP, Bharat Gas	A64 ◯ 1- yes ◯ 2- no	A65 _____
Gram Sabha	A66 ◯ 1- yes ◯ 2- no	A67 _____

Schemes/campaigns?	Have you heard of these schemes/campaigns	If yes, from whom did you hear these schemes? Check all that apply
PAHAL	A68 ◯ 1- yes ◯ 2- No	A69 ◯ 1- TV/radio/newspapers ◯ 2- SHGs ◯ 3- through government officials/gram sabhas ◯ 4- NGOs ◯ 5- Spouse ◯ 6- Gas agency/dealers ◯ 7- others-

RGGLVY Rajiv Gandhi LPG Vitaran Yojana	A70 ◯ 1- yes ◯ 2- No	A71 ◯ 1- TV/radio/newspapers ◯ 2- SHGs ◯ 3- through government officials/gram sabhas ◯ 4- NGOs ◯ 5- Spouse ◯ 6- Gas agency/dealers ◯ 7- others
Deepam	A72 ◯ 1- yes ◯ 2- No	A73 ◯ 1- TV/radio/newspapers ◯ 2- SHGs ◯ 3- through government officials/gram sabhas ◯ 4- NGOs ◯ 5- Spouse ◯ 6- Gas agency/dealers ◯ 7- others
GiveitUp campaign	A74 ◯ 1- yes ◯ 2- No	A75 ◯ 1- TV/radio/newspapers ◯ 2- SHGs ◯ 3- through government officials/gram sabhas ◯ 4- NGOs ◯ 5- Spouse ◯ 6- Gas agency/dealers ◯ 7- others
Pradhan Mantri Ujjwala Yojana	A76 ◯ 1- yes ◯ 2- No	A77 ◯ 1- TV/radio/newspapers ◯ 2- SHGs ◯ 3- through government officials/gram sabhas ◯ 4- NGOs ◯ 5- Spouse ◯ Gas agency/dealers ◯ 6- other

Now, we will ask you questions on your perceptions about LPG.

A78 Are you worried about LPG cylinder explosions?
◯ 1- yes
◯ 2- no
◯ 3- Can't say

A79 if "Yes" in A 78; does this worry influence or might influence adoption of LPG
◯ 1- yes
◯ 2- no
◯ 3- Can't say

.

A80 Which fuel use results in less emissions of gas?
- ◯ 1- LPG
- ◯ 2- biomass
- ◯ 3- kerosene
- ◯ 4- Can't say

A81 Which fuel use results in less strain in eyes while cooking?
- ◯ 1- LPG
- ◯ 2- biomass
- ◯ 3- kerosene
- ◯ 4- Can't say

A82 Which fuel use results in less choking while cooking?
- ◯ 1- LPG
- ◯ 2- biomass
- ◯ 3- kerosene
- ◯ 4- Can't say

A83 Which fuel use results in fewer burns while cooking?
- ◯ 1- LPG
- ◯ 2- biomass
- ◯ 3- kerosene
- ◯ 4- Can't say

A84 Which fuel use results in cleaner cooking place?
- ◯ 1- LPG
- ◯ 2- biomass
- ◯ 3- kerosene
- ◯ 4- Can't say

A85 Which fuel use results in faster cooking?
- ◯ 1- LPG
- ◯ 2- biomass
- ◯ 3- kerosene
- ◯ 4- Can't say

A86 Do you think use of LPG against your cultural practices related to cooking?
- ◯ 1- Yes
- ◯ 2- No
- ◯ 3- Can't say

A87 Does the use of newer cooking technologies bring enhanced social recognition in your community?
- ◯ 1- yes
- ◯ 2- no
- ◯ 3- can't say

A88 Use of which of these stoves bring enhanced social status in your community (check all that apply)
- ◯ 1- LPG
- ◯ 2- biomass
- ◯ 3- kerosene

◯ 4- Can't say

Following questions are to be asked to the primary respondents from the LPG adopter households (group 1) only.

.

LPG Ownership and refills

Note: Although asked to the woman respondent, the questions pertain to the entire household unless otherwise specifically mentioned.

A89 What type of LPG stoves do you have? (Enumerators please check the stove to validate)

◯ 1 single pot
◯ 2-double pot
◯ 3-Both single pot and double stoves

A90 Through which scheme did you receive your LPG connection? (check all that apply) (Enumerators, please check from the connection card)

◯ 1- Deepam
◯ 2- Pradhan Mantri Ujjwala Yojana
◯ 3- no scheme
◯ 4- any other scheme

A91 How long back in months did you apply for your first LPG connection? _____

A92 How long back in months did you receive your first LPG connection? (Enumerators, please check the LPG connection cards) _____

A93 How many LPG connections do you have? (Enumerators, please check the LPG connection cards) _____

A94 Do you have any LPG connection on your name? (Enumerators, please check the LPG connection cards)

◯ 1- yes
◯ 2- no

A95 When was the last time you refilled your LPG cylinder? (Enumerators, please check the LPG connection cards)

◯ 1- never as of yet
◯ 2- within last 1 month
◯ 3- within last 2 months
◯ 4- within last 3 months
◯ 5- within last 4 months
◯ 6- prior to last 4 months

A96 Is a refilled cylinder always available at the LPG distribution center?

- ◯ 1- yes
- 2- No

A97 what is the wait period before you receive a refill?

- ◯ 1- within 1 day
- ◯ 2- within 1 week
- ◯ 3- within 1 month
- ◯ 4- more than a month

A98 What was the upfront cost you paid for the first LPG connection? _____

A99 What is the cost for each refill? _____

A100 How do you normally transport LPG cylinders for refill to distribution centers and back to your house?

- ◯ 1- LPG agency home delivery
- ◯ 2- self-delivery in an owned vehicle
- ◯ 3- self-delivery in a hired vehicle
- ◯ 4- have not refilled as of yet

A101 How much is the delivery charges per delivery? _____

A102 Did you take bank loans for LPG connection?

- ◯ 1- yes
- ◯ 2- No

A103 Did you take loans from SHG for LPG connection?

- ◯ 1- yes
- ◯ 2- no

LPG use and stacking

A104 In last 1 year, which of these stoves have you normally used during summer for cooking after acquiring LPG connection? Check all that apply.

- ◯ 1- LPG
- ◯ 2- traditional stoves
- ◯ 3- kerosene stoves
- ◯ 4- improved biomass stoves
- ◯ 5- Electric induction stoves

A105 In last 1 year, which of these stoves have you normally used during winter for cooking after acquiring LPG connection? Check all that apply.

- ◯ 1- LPG
- ◯ 2- traditional stoves
- ◯ 3- kerosene stoves
- ◯ 4- improved biomass stoves
- ◯ 5- Electric induction stoves

A106 In last 1 year, which of these stoves have you normally used during monsoon for cooking after acquiring LPG connection? Check all that apply.

- ◯ 1- LPG
- ◯ 2- traditional stoves
- ◯ 3- kerosene stoves
- ◯ 4- improved biomass stoves
- ◯ 5- Electric induction stoves

A107 In last 1 year, estimate the total number of hours of cooking per day you do during summer _____

A108 In last 1 year, estimate the total number of hours of cooking per day you do on LPG during summer. _____

A109 In last 1 year, estimate the total number of hours of cooking per day you do during winter. _____

A110 In last 1 year, estimate the total number of hours of cooking per day you do on LPG during winter. _____

A111 In last 1 year, estimate the total number of hours of cooking per day you do during monsoon _____

A112s In last 1 year, estimate the total number of hours of cooking per day you do on LPG during monsoon _____

Appendix 8: Personal network survey for women

RedCap ID	_____
Form version	_____
Initials of person doing entry	_____
Tester initials	_____
G1 Date of interview-day	_____
G1 Date of interview-month	_____
G1 Date of interview-year	_____
G2 Mandal ID	◯ 1- Peddamandyam ◯ 2- Thambalpalle
G3 Habitation ID	_____
G4 Household ID	_____
All the above information will automatically populate in RedCap system.	

Woman (primary cook of the household) will be the respondent of this questionnaire.

Note to Respondents: This questionnaire mostly pertains to your relationship with other people in terms of your discussion on important personal matters.

Name generator of alters

G5. From time to time, most people discuss important personal matters with other people. Looking back over the last 6 months, who are the adults with whom you discussed an important personal matter? Also from time to time, people socialize with other people. For instance, they visit each other; go together on a trip or to a dinner. In the last 6 months, who are the adults with whom you usually do these things? Please just tell me their first names or initials.

N1_____	N6_____
N2_____	N7_____
N3_____	N8_____
N4_____	N9_____

N5_____	N10_____

G6 From time to time, people socialize with other people. For instance, they visit each other; go together on a trip or to a dinner. In the last 6 months, who are the adults with whom you usually do these things? Please just tell me their first names or initials. Don't worry about duplicates. We will deal with them after you are done.

N11_____	N16_____
N12_____	N17_____
N13_____	N18_____
N14_____	N19_____
N15_____	N20_____

If there are duplicates in G5 and G6 Names: Is [NAME] the same as [NAME] who you listed before? If fewer than five names are given, enumerators should probe for more and note them as well in above two questions.

.

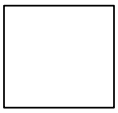
G7 Enumerators, please consolidate names from G5 and G6, removing any duplicates. Please put their initials after each names. For instance: Praveen Kumar (PK)

N1_____	N6_____
N2_____	N7_____
N3_____	N8_____
N4_____	N9_____
N5_____	N10_____

N11_____	N16_____
N12_____	N17_____
N13_____	N18_____
N14_____	N19_____

N15_____	N20_____

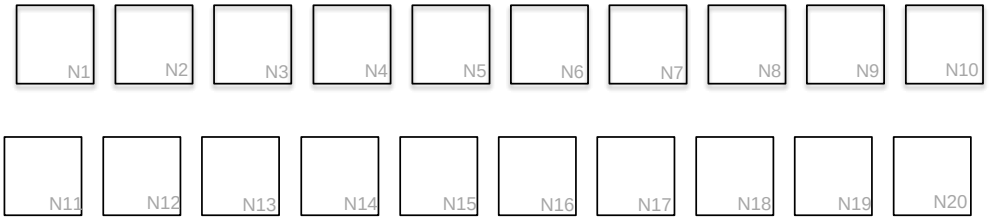
G8 If greater than 20 names mentioned, then Enumerators should record the total number of people named in the follow box



Name interpreter

G9. Compared to the names you mentioned in G7, whom do you feel especially close to [NAME 1]? Do you feel especially close to [NAME 2]? *Repeat for each name.*

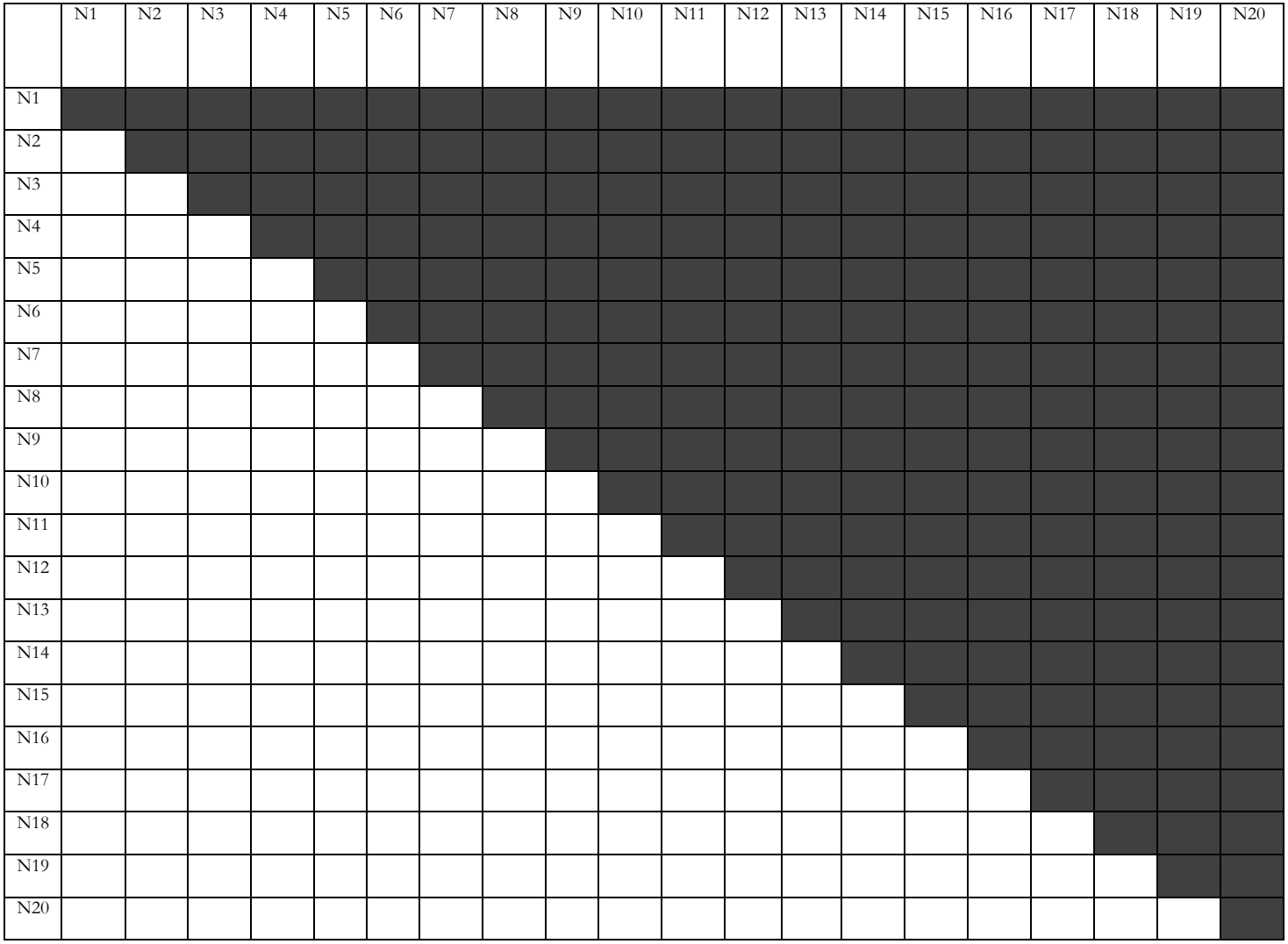
1- Yes, especially close
2- No



Alter-Alter relationships

G10. I will now focus on the relations between each pair of people you mentioned in G7. For example, I will ask about [Name 1] and [Name 2]. For each pair, I will ask whether they are: 1) total strangers; 2) especially close; 3) or in-between. By total strangers, I mean that they wouldn't recognize one another if they met on the street. By especially close, I mean as close to each other as they are to you. By in-between, I mean all other relationships. Do you understand?

Is [NAME 1] a total stranger, especially close, or in-between with [NAME 2]?
Enumerators, repeat for each pair of names.
Enumerators please fill the following this matrix with options: 1) total strangers; 2) especially close; 3) in-between.
You can use the initials of the names (from G7) here for quick identification



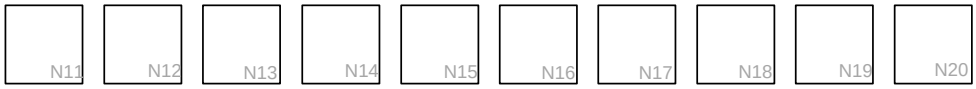
	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20
N1																				
N2																				
N3																				
N4																				
N5																				
N6																				
N7																				
N8																				
N9																				
N10																				
N11																				
N12																				
N13																				
N14																				
N15																				
N16																				
N17																				
N18																				
N19																				
N20																				

Alter attributes

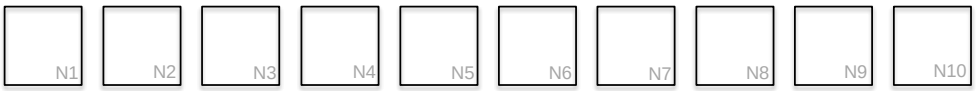
G11: Is [NAME 1] a male or female? And [NAME 2]? **…**

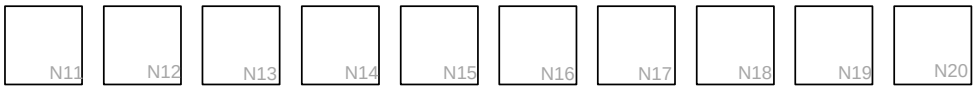
1. Male

2. Female



G12: What is the age of [NAME 1] ? And [NAME 2]? …



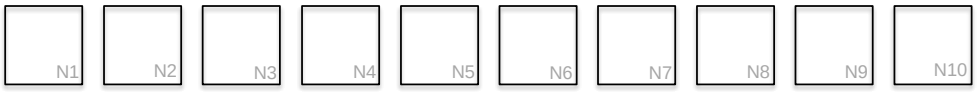


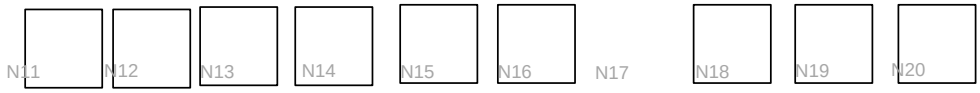
G13: As far as you know, what is [NAME 1]'s highest level of education? And [NAME 2]? …

1 none
2 up to class 4
3 class 5 to class 8

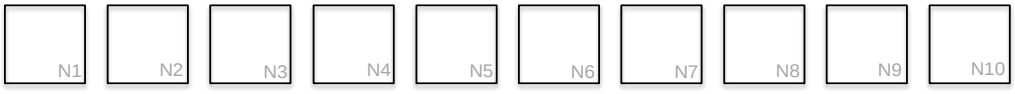
4 class 9 to class 10

5 class 11 to class 12
6 College
9- Don't know

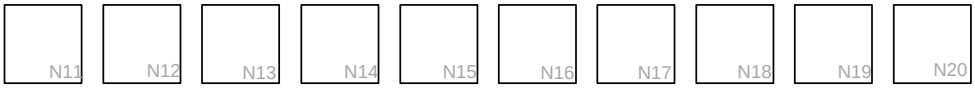




G14: Is [NAME 1] a member of any SHG? [NAME 2]…

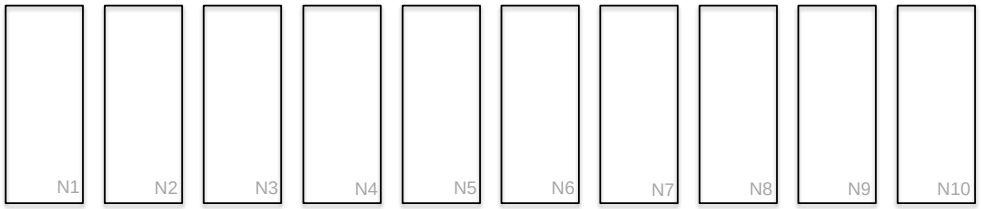


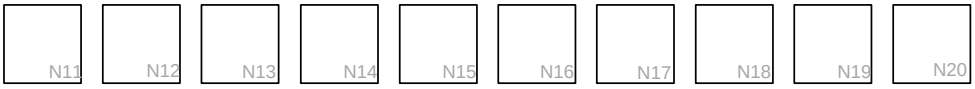
1- Yes
2- No



G15: I'm going to give you a list of some of the ways in which people are connected to each other. Some people can be connected to you in more than one way. For example, a man could be your brother. When I read you a name, please tell me all the ways that person is connected to you. How is [NAME 1] connected to you? And [NAME 2]? …

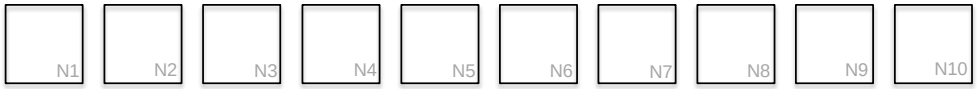
1. Spouse
2. Parent
3. Sibling
4. Child
5. Other family
6. Coworker
7. Co-member in org.
8. Neighbor
9. Friend
10. Advisor
11. Other
99. Don't know

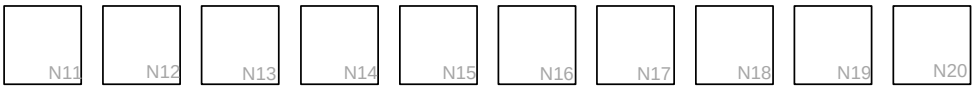




G16: Does [NAME 1] have an LPG connection? And [NAME 2]? …

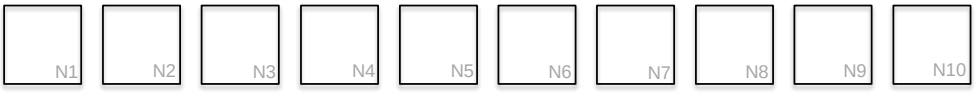
1. Yes
2. No
9. Don't know



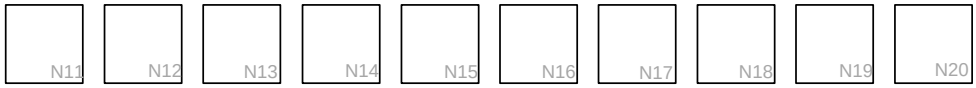


G17: How many connections does [NAME 1] have? And [NAME 2]? …

1. 1
2. 2
3. 3



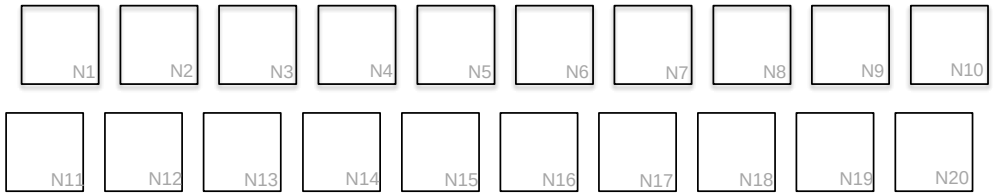
4. 4
5. 5
6. 6
7. More than 6
9. don't know
10. 0



G18: For each of them, if they own LPG cylinders, does [NAME 1] use only LPG, or both LPG and other stoves such as biomass or kerosene? And [NAME 2]? …

1. only LPG
2. Both LPG and other stoves
3. Does not own LPG
9. don't know

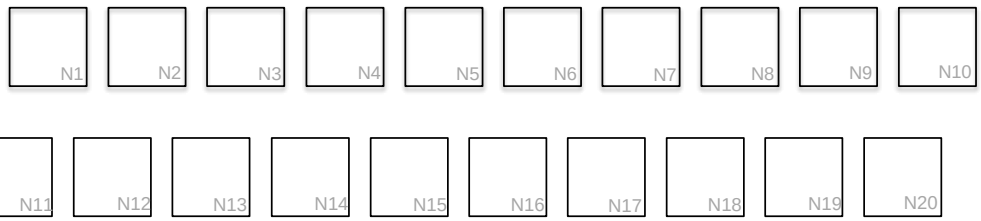
G19: What is the average income per month of [NAME 1]'s household? And [NAME 2]? …



1- less than 500
2- equal to or more than 500 less than 2000
3- equal to or more than 2000 less than 5000
4- equal to or more than 5000 less than 10000
5- equal to or more than 10000
9- Don't know

G20: As far as you know, what is [NAME 1]'s marital status? And [NAME 2]? …

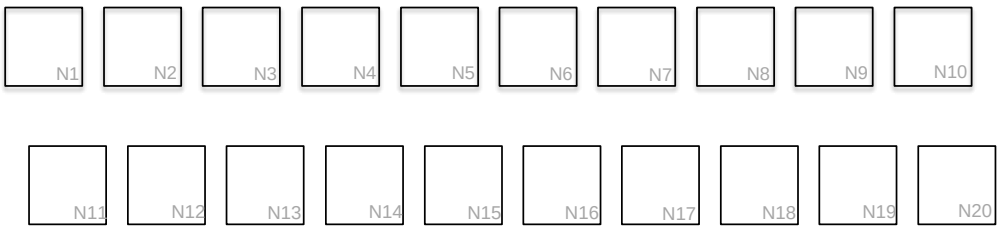
1- married
2- Unmarried
3- Widow
4- Divorced



9- Don't know

G21: On average, do you speak with [NAME 1] almost every day, at least once a week, at least once a month, or less than once a month? And [NAME 2]? …

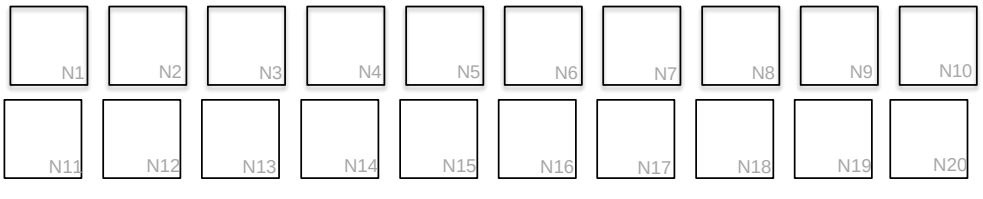
1. Daily
2. Weekly
3. Monthly
4. less often



9. Don't know

G22: What is [NAME 1]'s caste? And [Name 2]? …

1. General
2. SC/ST
3. OBC

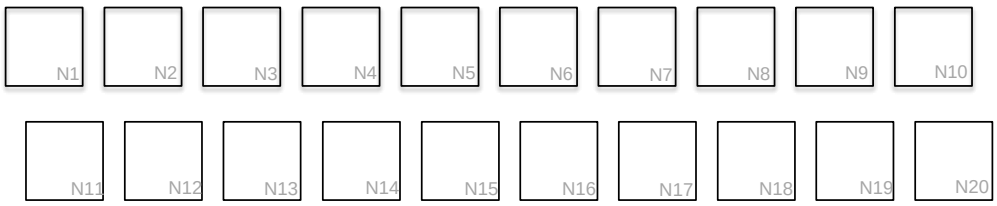


4. Other religious minorities

5. Others

9. Don't know

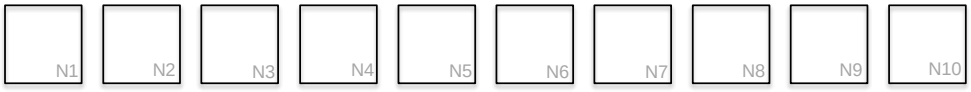
G23: What is the number of family members living in [NAME 1]'s household? And [NAME 2]? 1ಎ



G24: What is the occupation of [NAME 1]? And [NAME 2]? …

1 home maker

2 Self-employed: farm



3 self-employed: non-farm

4 agricultural labor

5 Non-agricultural labor

6 Other

9- Don't know

N11 N12 N13 N14 N15 N16 N17 N18 N19 N20

G25: Does [NAME 1] accompany you in group activities like accompanying for biomass collection, going for drinking, cigarettes etc.? [NAME 2]…

1- Yes

2- No

N11 N12 N13 N14 N15 N16 N17 N18 N19 N20

N1 N2 N3 N4 N5 N6 N7 N8 N9 N10

G26: How far away does [NAME 1] live? And [NAME 2]?

1. Same house

2. Less than 5 km

N1 N2 N3 N4 N5 N6 N7 N8 N9 N10

3. Equal to or more than 5 km less than 10 km

4. Equal to or more than 10 less than 20

5. Equal to or more than 20 km

9. Don't know

N11 N12 N13 N14 N15 N16 N17 N18 N19 N20

CARD for G15

Spouse: Your wife, your husband, or a person with whom you are living as if married.
Parent: Your father or mother.
Sibling: Your brother or sister.
Child: Your son or daughter.
Other family: For example, grandparent, grandchild, cousin, aunt, uncle, nephew, niece, or an in-law.
Coworker: Someone who works with you, or usually meet while working.
Co-member in organization: Someone who is a member of the same organization as you. For example, a person who attends the same mosque, temple etc., attends the same school, or belongs to the same club.
Neighbor: Someone outside your own household who lives close to you in your neighborhood.
Friend: Someone who you get together with for informal social occasions.

Professional advisor or consultant: A trained expert who gives you advice. For example, a lawyer or a priest.

Appendix 9: Personal network survey for men

RedCap ID	_____
Form version	_____
Initials of person doing entry	_____
Tester initials	_____
G1 Date of interview-day	_____
G1 Date of interview-month	_____
G1 Date of interview-year	_____
G2 Mandal ID	◯ 3- Peddamandyam ◯ 4- Thambalpalle
G3 Habitation ID	_____
G4 Household ID	_____
All the above information will automatically populate in RedCap system.	

Primary male decision maker of the household will be the respondent of this questionnaire.

Note to Respondents: This questionnaire mostly pertains to your relationship with other people in terms of your discussion on important personal matters.

Name generator of alters

G5. From time to time, most people discuss important personal matters with other people. Looking back over the last 6 months, who are the adults with whom you discussed an important personal matter? Also from time to time, people socialize with other people. For instance, they visit each other; go together on a trip or to a dinner. In the last 6 months, who are the adults with whom you usually do these things? Please just tell me their first names or initials.

N1_____	N6_____
N2_____	N7_____
N3_____	N8_____
N4_____	N9_____
N5_____	N10_____

G6 From time to time, people socialize with other people. For instance, they visit each other; go together on a trip or to a dinner. In the last 6 months, who are the adults with whom you usually do these things? Please just tell me their first names or initials. Don't worry about duplicates. We will deal with them after you are done.

N11_____	N16_____
N12_____	N17_____
N13_____	N18_____
N14_____	N19_____
N15_____	N20_____

If there are duplicates in G5 and G6 Names: Is [NAME] the same as [NAME] who you listed before? If fewer than five names are given, enumerators should probe for more and note them as well in above two questions.

.

G7 Enumerators, please consolidate names from G5 and G6, removing any duplicates. Please put their initials after each names. For instance: Praveen Kumar (PK)

N1_____	N6_____
N2_____	N7_____
N3_____	N8_____
N4_____	N9_____
N5_____	N10_____

N11_____	N16_____
N12_____	N17_____
N13_____	N18_____
N14_____	N19_____
N15_____	N20_____

G8 If greater than 20 names mentioned, then Enumerators should record the total number of people named in the follow box

Name interpreter

G9. Compared to the names you mentioned in G7, whom do you feel especially close to [NAME 1]? Do you feel especially close to [NAME 2]? *Repeat for each name.*

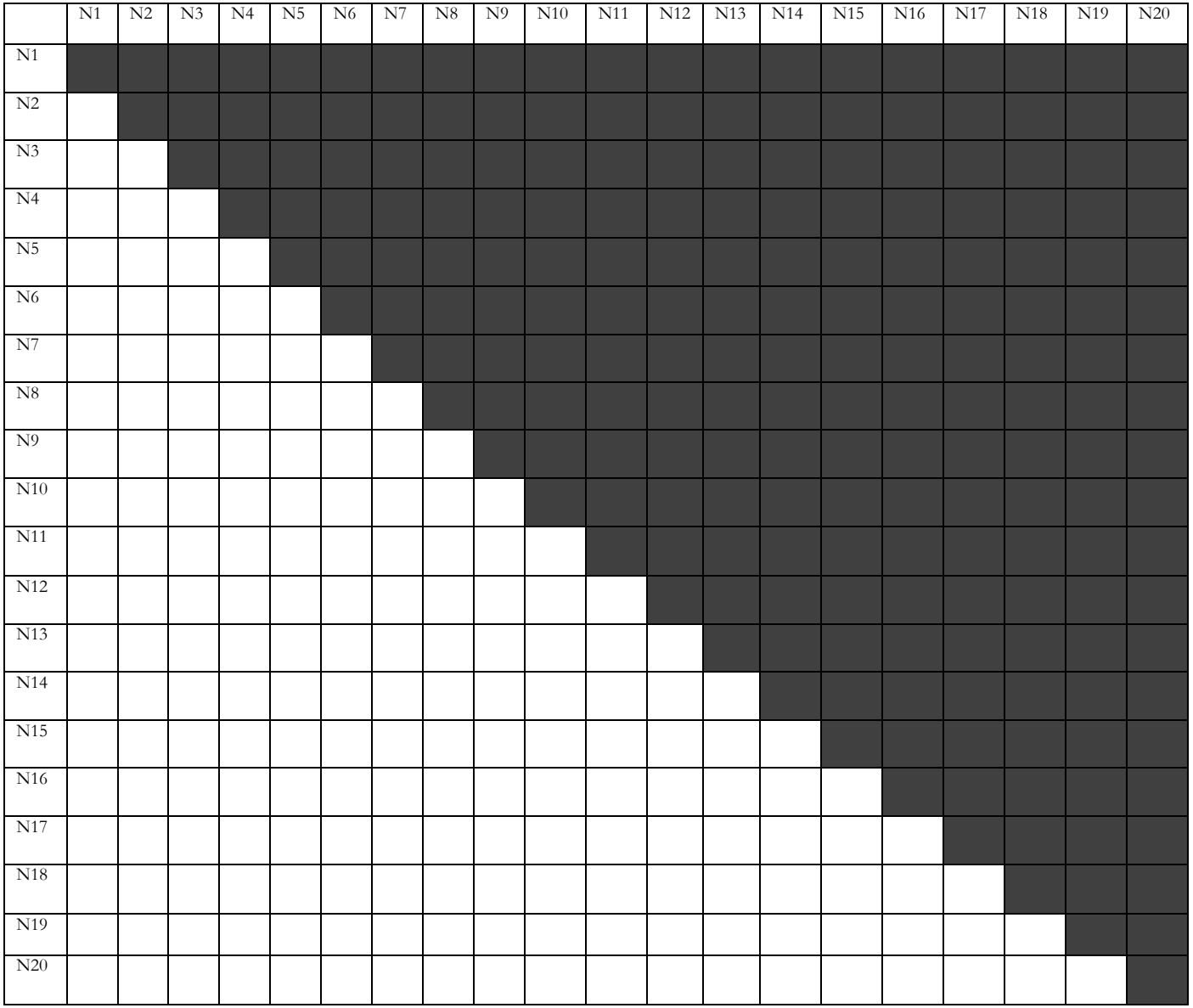
1- Yes, especially close
2- No

N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N11	N12	N13	N14	N15	N16	N17	N18	N19	N20

Alter-Alter relationships

G10. I will now focus on the relations between each pair of people you mentioned in G7. For example, I will ask about [Name 1] and [Name 2]. For each pair, I will ask whether they are: 1) total strangers; 2) especially close; 3) or in-between. By total strangers, I mean that they wouldn't recognize one another if they met on the street. By especially close, I mean as close to each other as they are to you. By in-between, I mean all other relationships. Do you understand?

Is [NAME 1] a total stranger, especially close, or in-between with [NAME 2]?
Enumerators, repeat for each pair of names.
Enumerators please fill the following this matrix with options: 1) total strangers; 2) especially close; 3) in-between.
You can use the initials of the names (from G7) here for quick identification

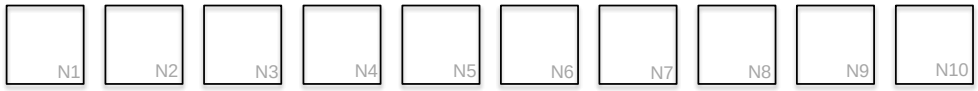


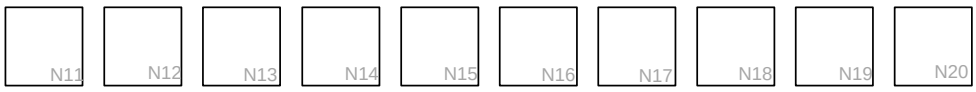
Alter attributes

G11: Is [NAME 1] a male or female? And [NAME 2]? **…**

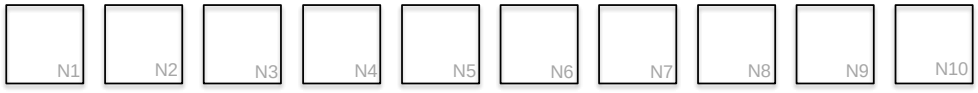
1. Male

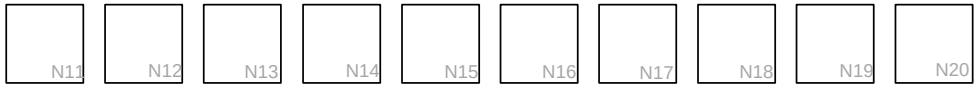
2. Female





G12: What is the age of [NAME 1] ? And [NAME 2]? …



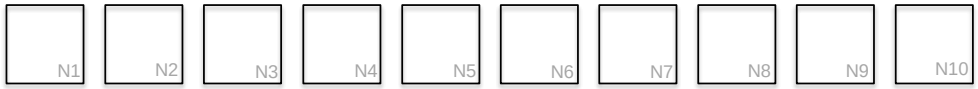


G13: As far as you know, what is [NAME 1]'s highest level of education? And [NAME 2]? …

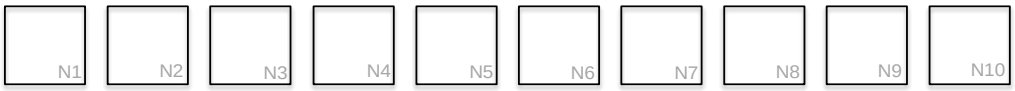
1- none
2- up to class 4
3- class 5 to class 8

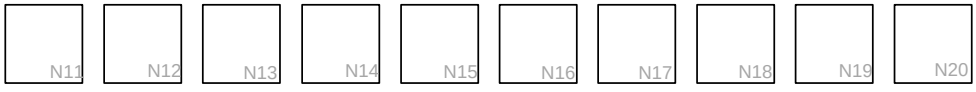
4- class 9 to class 10

5- class 11 to class 12
6- College
9- Don't know



G14: Is [NAME 1] a member of any SHG? [NAME 2]…





1- Yes
2- No

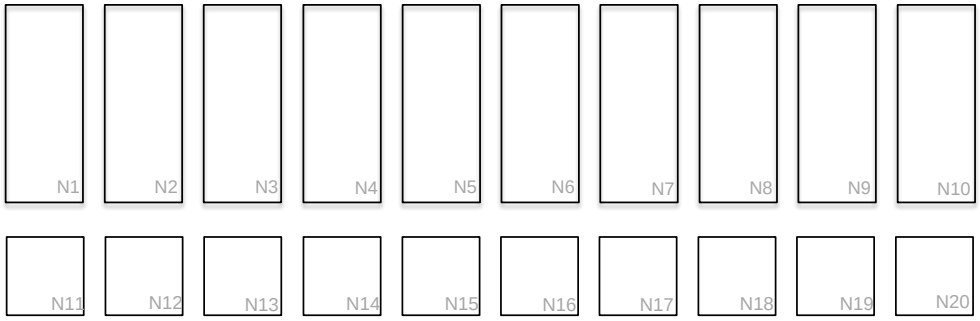
G15: I'm going to give you a list of some of the ways in which people are connected to each other. Some people can be connected to you in more than one way. For example, a man could be your brother. When I read you a name, please tell me all the ways that person is connected to you. How is [NAME 1] connected to you? And [NAME 2]? …

1. Spouse

2. Parent

3. Sibling

4. Child



5. Other family

6. Coworker

7. Co-member in org.

8. Neighbor

9. Friend

10. Advisor

11. Other

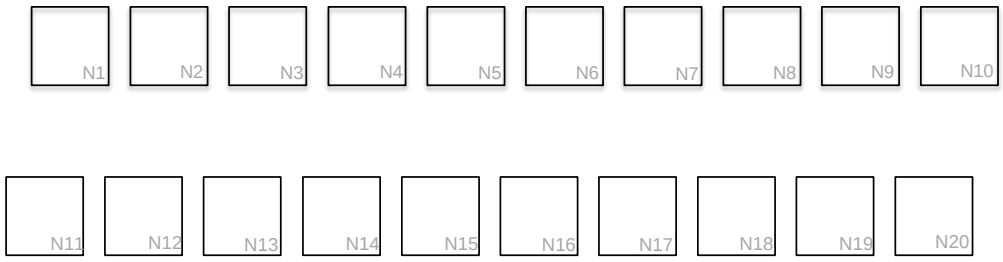
99. Don't know

G16: Does [NAME 1] have an LPG connection? And [NAME 2]? …

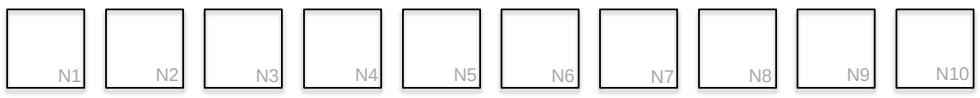
1. Yes

2. No

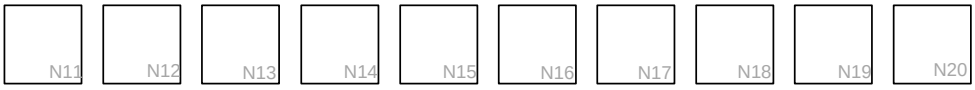
9. Don't know



G17: How many connections does [NAME 1] have? And [NAME 2]? …

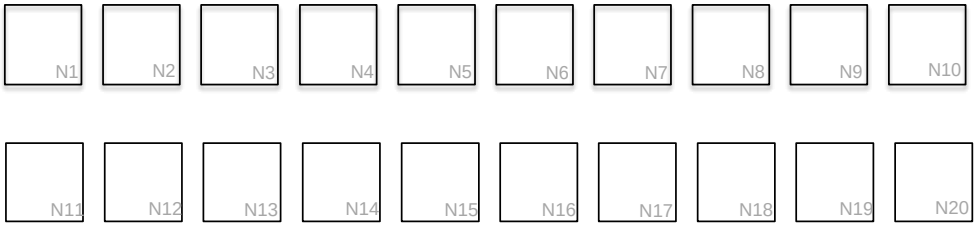


1- 1
2- 2
3- 3
4- 4
5- 5
6- 6
7- More than 6
11. don't know
12. 0

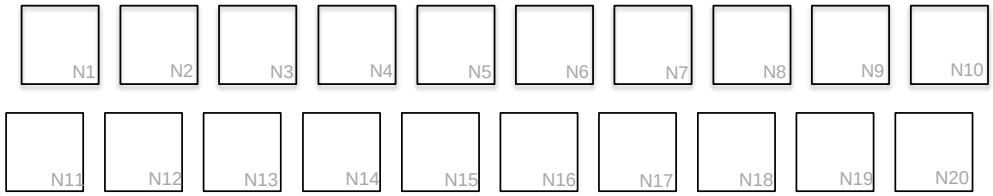


G18: For each of them, if they own LPG cylinders, does [NAME 1] use only LPG, or both LPG and other stoves such as biomass or kerosene? And [NAME 2]? …

1- only LPG
2- Both LPG and other stoves
3- Does not own LPG
10. don't know



G19: What is the average income per month of [NAME 1]'s household? And [NAME 2]? …



1- less than 500
2- equal to or more than 500 less than 2000
3- equal to or more than 2000 less than 5000
4- equal to or more than 5000 less than 10000
5- equal to or more than 10000
10- Don't know

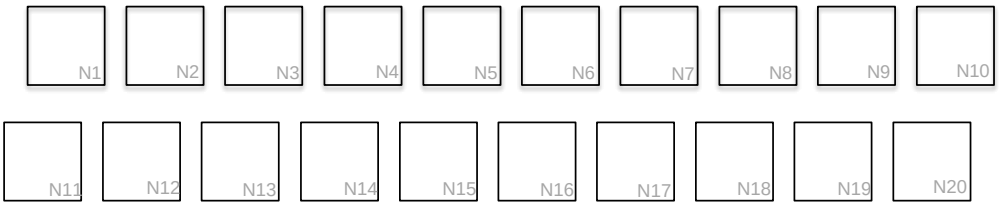
G20: As far as you know, what is [NAME 1]'s marital status? And [NAME 2]? …

1- married

2- Unmarried

3- Widow

4- Divorced



9- Don't know

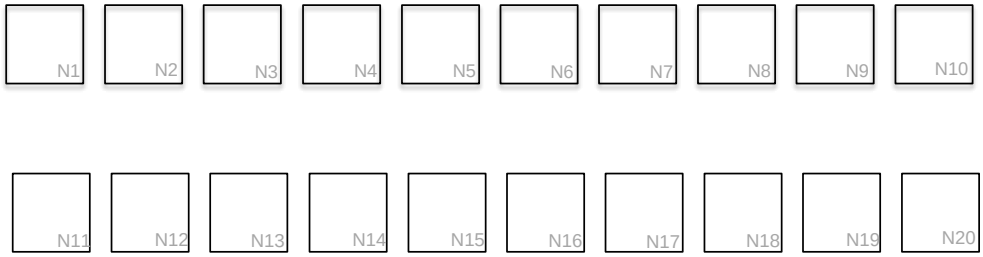
G21: On average, do you speak with [NAME 1] almost every day, at least once a week, at least once a month, or less than once a month? And [NAME 2]? …

1- Daily

2- Weekly

3- Monthly

4- less often



9. Don't know

G22: What is [NAME 1]'s caste? And [Name 2]? …

1. General

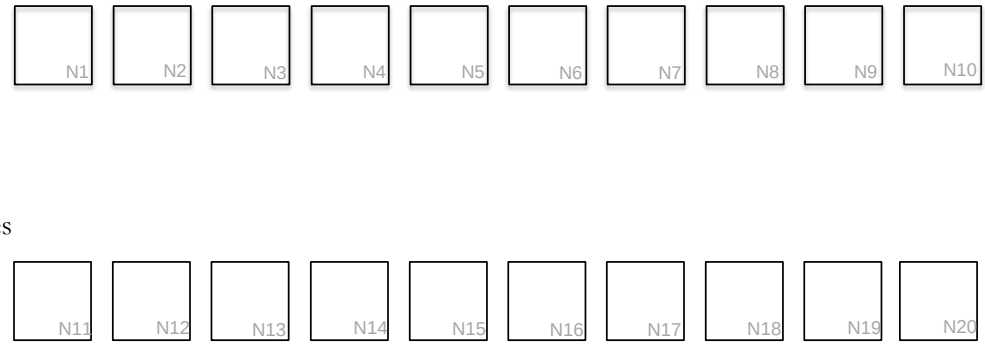
2. SC/ST

3. OBC

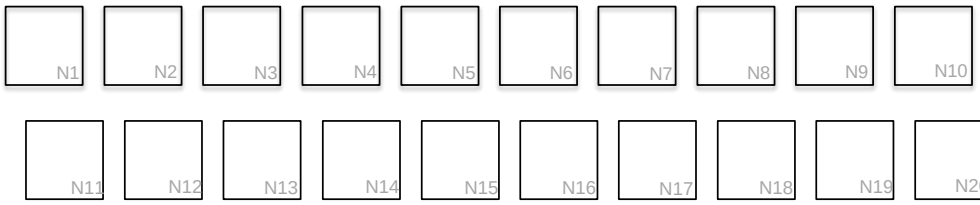
4. Other religious minorities

5. Others

9. Don't know

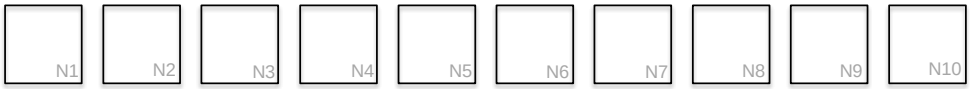


G23: What is the number of family members living in [NAME 1]'s household? And [NAME 2]? 1ఎ



G24: What is the occupation of [NAME 1]? And [NAME 2]? …

1 home maker



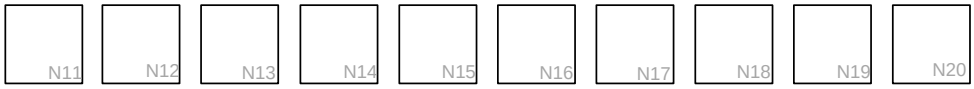
2 Self-employed: farm

3 self-employed: non-farm

4 agricultural labor

5 Non-agricultural labor

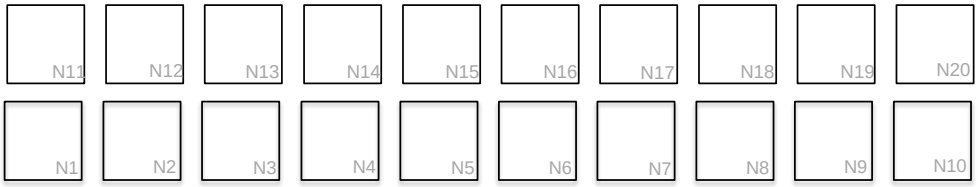
6 Other



9- Don't know

G25: Does [NAME 1] accompany you in group activities like accompanying for biomass collection, going for drinking, cigarettes etc.? [NAME 2]…

1- Yes

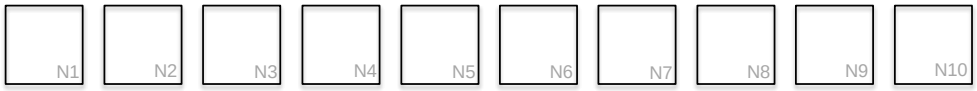


2- No

G26: How far away does [NAME 1] live? And [NAME 2]?

1. Same house

2. Less than 5 km



3. Equal to or more than 5 km less than 10 km

4. Equal to or more than 10 less than 20

5. Equal to or more than 20 km

9. Don't know

N11	N12	N13	N14	N15	N16	N17	N18	N19	N20

CARD for G15

Spouse: Your wife, your husband, or a person with whom you are living as if married.
Parent: Your father or mother.
Sibling: Your brother or sister.
Child: Your son or daughter.
Other family: For example, grandparent, grandchild, cousin, aunt, uncle, nephew, niece, or an in-law.
Coworker: Someone who works with you, or usually meet while working.
Co-member in organization: Someone who is a member of the same organization as you. For example, a person who attends the same mosque, temple etc., attends the same school, or belongs to the same club.
Neighbor: Someone outside your own household who lives close to you in your neighborhood.
Friend: Someone who you get together with for informal social occasions.

Professional advisor or consultant: A trained expert who gives you advice. For example, a lawyer or a priest.

Appendix 10: Informed consent document

Project Title: Understanding household, network, and organizational drivers of adoption, sustained use, and maintenance of clean cooking fuels in rural India
Principal Investigator: Gautam Yadama (yadama@wustl.edu, 314-935-5698)
Research Team Contact: Sandeep K (Phone: +91-9849304274) and R. Kaushal Rao (Phone: +91- 9963620151)

- If you are over the age of 18 and reading this document, the word "you" in this document refers to you and your spouse/senior most male member of this household/primary male decision maker of this household. You and your spouse/senior most male member of this household/primary male decision maker of this household will be asked to read and sign this document to indicate your willingness to participate.

This consent form describes the research study and helps you decide if you want to participate. It provides important information about what you will be asked to do during the study, about the risks and benefits of the study, and about your rights as a research participant. By signing this form, you are agreeing to participate in this study.

- If you have any questions about anything in this form, you should ask the research team for more information.
- You may also wish to talk to your family or friends about your participation in this study.
- Do not agree to participate in this study unless the research team has answered your questions and you decide that you want to be part of this study.

WHAT IS THE PURPOSE OF THIS STUDY?

We invite you to participate in this research study because you are the primary cook for this household, your family has resided in this household for the last 12 months, you plan to reside in this household at least for 12 months from the current date, and you use a traditional wood burning cook stove, or an LPG stove, or both for cooking. If you have an LPG connection, you received your first LPG connection in the last 12 months. The purpose of this research study is to understand the reach of LPG among the poor in rural India, factors that influence adoption (initial uptake), sustained use, and maintenance of LPG in below poverty line (BPL) households in rural India.

WHAT WILL HAPPEN DURING THIS STUDY?

Depending on whether you own an LPG or not, you will be categorized into two groups:
Case group: If you have an LPG connection, you will be categorized in case group households. If you meet our inclusionary criteria, an informed consent will be provided to you and to your spouse/senior most male member of this household/primary male decision maker of this household to agree and sign. We will then administer a set of questionnaires for you and your spouse/senior most male member of this household/primary male decision maker of this household to respond. We will request for data on your household demographics, social networks, and factors affecting your decision on fuel choices for cooking. If yours household is in case group, we will seek your consent to use Stove use monitoring systems (SUMS) for monitoring your stove usage. We will prepare a list of all those case group households who consent for SUMS monitoring. We will randomly select 100 households from this list. If your house is chosen for monitoring of your usage

of stoves, we will install these stove use monitor technologies on your LPG stoves and traditional stoves to monitor how much you use these stoves at normal routine practices. We will monitor your usage patterns for 12 months. During the monitoring period, after 6 months and then after 12 months, we will administer a follow up questionnaire. This questionnaire will record data on your household demographics, and factors affecting sustained use of LPG stoves compared to traditional stoves.

Control group: If you currently do not have an LPG connection and cook on traditional stoves, you will be categorized in control group households. If you meet our inclusionary criteria, an informed consent will be provided to you and to your spouse/senior most male member of this household/primary male decision maker of this household to agree and sign. We will then administer a set of questionnaires for you to respond. We will request for data on your household demographics, social networks, and factors affecting your decision on fuel choices for cooking.

HOW MANY PEOPLE WILL PARTICIPATE?

255 case group households and 255 control group households will participate in the study. Randomly selected 100 households out of those case group households, who consented for SUMS monitoring, will be deployed with Stove use monitoring systems (SUMS) on their LPG and traditional stoves.

STUDY VISITS

Visit 1: During visit 1, if your household meets eligibility criteria you will be given an informed consent to review and sign. Irrespective of your household in case or control group, we will ask you questions about your household demographics, factors affecting your decision on fuel choices for cooking, and your social networks. We will ask questions with your spouse/senior most male member of this household/primary male decision maker of this household, on his social networks. We will conclude control group participation in the study after administering these surveys.

Subsequent visits to select LPG adopter households: Randomly selected 100 case group households, who consented for monitoring, will be deployed with SUMS technologies. If you are in this group of 100 households, our experienced field worker will visit you every two weeks to download the data from SUMS using a probe, USB, and a laptop computer. These visits will continue till 12 months. One of the visits after 6 months and then after 12 months during monitoring will require you to answer questions on your household demographics, and factors affecting sustained use of LPG stoves relative to traditional stoves' use for the period of monitoring. Participation of households in the case group, who are not enrolled in SUMS monitoring, will be concluded after administering the surveys.

Study schedule

	2016							2017					
	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	March	April	May	June
Household consent	X	X											
Data collection from questionnaires for both case and		X	X	X	X								

	2016							2017					
	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	March	April	May	June
control groups													
SUMS monitoring for 100 case households		X	X	X	X	X	X	X	X	X	X	X	X

Photographs

We might take pictures mainly to record the size of the kitchen, placement of SUMS on stoves (for select case households). Only the research team will have access to the pictures. Pictures are only one aspect of the study. You can choose not to give us permission for the pictures and audio recordings and still participate in the study.

I give you permission to **photograph** me, the kitchen, and windows of the house during this study.

_____ Yes _____ No

Initials Initials

Time Commitments

	0 month	**6 months**	**12 months**
Adoption questionnaire	1 hour		
Social network survey for women	45 minutes		
Social network survey for men	45 minutes		
Follow up questionnaire	1 hour	45 minutes	45 minutes
Additional commitment for select 100 case group households under SUMS monitoring			
	0 months-12 months (every 2 weeks)		
SUMS data log sheet	20-30 minutes every 2 weeks		

WHAT ARE THE RISKS OF THIS STUDY?

You may experience one or more of the risks indicated below from being in this study. In addition to these, there may be other unknown risks, or risks that we did not anticipate, associated with being in this study.

Questionnaires:

Likely: Your participation will involve answering structured questions asked by a trained interviewer about social, economic, and social networks related aspects. Your responses to these questions will be coded to protect your confidentiality. You may get tired or bored when we are asking you questions. If any particular question makes you uncomfortable, you may discuss its importance and the need to answer it with the specially trained interviewer. You may choose not to answer any question with which you still feel uncomfortable.

Less Likely: None

Rare: None

SUMS monitoring

Likely: SUMS technologies may occasionally fall off from the stoves. You might have to let our field workers know, so that they may be re-install them on the stoves. Occasionally, SUMS might

stop working or might break down. Our field workers will replace them with new SUMS. There are no impacts on health or general well-being due to these SUMS usage. However, if you feel that they are bothering you in your daily cooking practices, you can request our field workers to take them off. We will discontinue monitoring in your household.

Less Likely: None

Rare: None

RISK MITIGATION

We have taken various measures to mitigate the risks involved. Regarding survey data collection, if any particular question makes you uncomfortable, you may discuss its importance and the need to answer it with the specially trained interviewer. You may choose not to answer any question with which you still feel uncomfortable. The completed surveys will be stored inside locked cabinets. The staff will use encrypted email, USB drives, and laptops to ensure that data is not compromised during data transfer. SUMS technologies installed on your stoves are safe and do not have any impact on your health or general well-being. If there are any effects on your well-being due to participation in the study, you will provide medical treatment at no cost. We will also contact Gautam Yadama (PI) regarding the issue.

What happens if you are injured because you took part in this study?

Washington University investigators and staff will try to reduce, control, and treat any complications from this research. If you feel you are injured because of the study, please contact the investigator Gautam Yadama at (314) 935-5698 and/or the Human Research Protection Office at 1-(800)-438-0445.

Decisions about payment for medical treatment for injuries relating to your participation in research will be made by Washington University. There is no program for compensation through the National Institutes of Health. If you need to seek medical care for a research-related injury, please notify the investigator as soon as possible.

WHAT ARE THE BENEFITS OF THIS STUDY?

There are no immediate tangible benefits to the study participants. Potential benefits of the study participation lie chiefly in the development of knowledge which will allow researchers and policy makers to create more effective interventions for dissemination and implementation of LPG in these resource poor settings. By participating in the study, respondents will contribute to advancement of knowledge about the determinants of the adoption and sustained use of LPG. Nevertheless, the research findings will be disseminated to community members, respondents, and leaders of the community local self government.

WHAT OTHER OPTIONS ARE THERE?

The only other option is to not participate in the study.

WILL IT COST ME ANYTHING TO BE IN THIS STUDY?

There are no financial costs to participating in this study.

WILL I BE PAID FOR PARTICIPATING?

You will not be paid for being in this research study.

WHO IS FUNDING THIS STUDY?

National Institutes of Health is funding this research study. This means that the Washington University is receiving payments from NIH to support the activities that are required to conduct the study. No one on the research team will receive a direct payment or increase in salary from NIH for conducting this study.

HOW WILL YOU KEEP MY INFORMATION CONFIDENTIAL?

We will keep your participation in this research study confidential to the extent permitted by law. However, it is possible that other people such as those indicated below may become aware of your participation in this study and may inspect and copy records pertaining to this research. Some of these records could contain information that personally identifies you.

- Federal government regulatory agencies,
- University representatives, to complete University responsibilities
- Washington University's Institutional Review Board (a committee that reviews and approves research studies)

To help protect your confidentiality, your identity will not be revealed in any publication that may result from this study. In rare instances, a researcher's study must undergo an audit or program evaluation by Washington University or an external oversight agency (such as the Office for Human Research Protection). This may result in the disclosure of your data as well as any other information collected by the researcher. Any information that has your name on it will be kept in a locked drawer or computer file that is protected with a password. Unless you say no, the researchers will keep a private list that links your ID number with your name. You can ask that we do not keep any information connecting your name with your ID number. If we write a report or article about this study or share the study data set with others, we will do so in such a way that you cannot be directly identified.

IS BEING IN THIS STUDY VOLUNTARY?

Taking part in this research study is completely voluntary. You may choose not to take part at all. If you decide to be in this study, you may stop participating at any time. If you decide not to be in this study, or if you stop participating at any time, you will not be penalized or lose any benefits for which you otherwise qualify.

What if I decide to withdraw from the study?

You may withdraw by telling the study team you are no longer interested in participating in the study.

Can someone else end my participation in this study?

Under certain circumstances, the researchers might decide to end your participation in this research study earlier than planned. This might happen because you decide to move or are unable to comply with study requirements.

WHAT IF I HAVE QUESTIONS?

We encourage you to ask questions. If you have any questions about the research study itself, please contact: **Sandeep K (Phone: +91-9849304274) and R. Kaushal Rao (Phone: +91- 9963620151)** from the FES Team. If you feel that you have been harmed in any way by your participation in this study, please contact the PI Gautam Yadama 314-935-5698.

If you have questions, concerns, or complaints about your rights as a research participant please contact the Human Research Protection Office, 660 South Euclid Avenue, Campus Box 8089, St. Louis, MO 63110, (1-(800)-438-0445 or email hrpo@wusm.wustl.edu. General information about being a research participant can be found by clicking "Participants" on the Human Research Protection Office web site, http://hrpohome.wustl.edu. To offer input about your experiences as a research participant or to speak to someone other than the research staff, call the Human Research Protection Office at the number above.

This consent form is not a contract. It is a written explanation of what will happen during the study if you decide to participate. You are not waiving any legal rights by agreeing to participate in this study.

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a signed copy of this form.

Do not sign this form if today's date is after EXPIRATION DATE: XX/XX/XXXX

_____ _____

Signature of Primary Respondent (women) (Date)

_____

Parent/Guardian Name of Primary Respondent:

_____ _____ (Date)

Signature of Primary Respondent's spouse/senior most
Male member of this household/primary male Decision maker of this household

_____

Parent/Guardian Name of primary respondent's spouse/senior most male member of this household/primary male decision maker of this household

<u>If your household is an LPG adopter household (case group), do you provide consent for us to monitor your stove usage with SUMS?</u>

_____

Signature of Primary Respondent (women)

<u>Statement of Person Who Obtained Consent</u>

The information in this document has been discussed with the participant. The participant has indicated that he or she understands the risks, benefits, and procedures involved with participation in this research study.

_____ _____

(Signature of Person who Obtained Consent) (Date)

_____

(Name of Person who Obtained Consent - printed)

Appendix 11: Approval letter from WUSTL IRB

Washington University in St. Louis

Human Research Protection Office

Barnes Jewish Hospital
St. Louis Children's Hospital
Washington University

IRB ID #: 201608013

To: Gautam Yadama

From: The Washington University in St. Louis Institutional Review Board,

WUSTL	DHHS Federalwide Assurance #FWA00002284
BJH	DHHS Federalwide Assurance #FWA00002281
SLCH	DHHS Federalwide Assurance #FWA00002282

Re: Understanding household, network, and organizational drivers of adoption, sustained use, and maintenance of clean cooking fuels in rural India

---

Approval Date: 09/01/16

Next IRB Approval

Due Before: 08/31/17

Type of Application:

☒ New Project
☐ Continuing Review
☐ Modification

Type of Application Review:

☐ Full Board:
Meeting Date:
☒ Expedited
☐ Exempt
☐ Facilitated

Approved for Populations:

☐ Children
  ☐ Signature from one parent
  ☐ Signature from two parents
☐ Prisoners
☐ Pregnant Women, Fetuses, Neonates
☐ Wards of State
☐ Decisionally Impaired

Criteria for approval are met per 45 CFR 46.111 and/or 21 CFR 56.111 as applicable.

Project determined to be minimal risk per 45 CFR 46.102(i) and/or 21 CFR 56.102(i) as applicable.

Source of Support:
DHHS, National Institutes of Health
ReCLAIM

MATERIALS APPROVED

Consent/Assent Materials:
Consent & Assent Forms
Consent form translated_men_sept 1_V2-1.rtf
Consent form translated_women_sept 1_v2-1.rtf
Informed consent document_men_sept 1.rtf
Informed consent document_women_sept 1.rtf
Recruitment/Advertisement Materials:
Recruitment: Group Presentation
Recruitment Material_Aug 19.docx
Questionnaires:
Subject Data Collection Instruments
lpg adoption questionnaire_translated.docx
LPG Adoption Questionnaire.docx
Follow up questionnaire-6 months.docx
Follow up questionnaire-12 months.docx
Follow up questionnaire- 12 months_translated.docx
Follow up questionnaire-6 months_translated.docx
SUMS Data Log Sheet.docx
Relative/Proxy Data Collection Instruments
SNA questionnaire_men.docx
SNA Questionnaire_women.docx
SNA_men_translated.docx
SNA_women_translated.docx

This approval has been electronically signed by IRB Chair or Chair Designee:

Jackie Cleary, BA

09/01/16 1421

IRB Approval: IRB approval indicates that this project meets the regulatory requirements for the protection of human subjects. IRB approval does not absolve the principal investigator from complying with other institutional, collegiate, or departmental policies or procedures.

Recruitment/Consent: Your IRB application has been approved for recruitment of subjects not to exceed the number indicated on your application form. If you are using written informed consent, the IRB-approved and stamped Informed Consent Document(s) are available in *my*IRB. The original signed Informed Consent Document should be

placed in your research files. A copy of the Informed Consent Document should be given to the subject. (A copy of the *signed* Informed Consent Document should be given to the subject if your Consent contains a HIPAA authorization section.)

Continuing Review: Federal regulations require that the IRB re-approve research projects at intervals appropriate to the degree of risk, but no less than once per year. This process is called "continuing review." Continuing review for non-exempt research is required to occur as long as the research remains active for long-term follow-up of research subjects, even when the research is permanently closed to enrollment of new subjects and all subjects have completed all research-related interventions and to occur when the remaining research activities are limited to collection of private identifiable information. Your project "expires" at midnight on the date indicated on the preceding page ("Next IRB Approval Due on or Before"). You must obtain your next IRB approval of this project by that expiration date. You are responsible for submitting a Continuing Review application in sufficient time for approval before the expiration date, however you will receive reminder notice prior to the expiration date.

Modifications: Any change in this research project or materials must be submitted on a Modification application to the IRB for prior review and approval, except when a change is necessary to eliminate apparent immediate hazards to subjects. The investigator is required to promptly notify the IRB of any changes made without IRB approval to eliminate apparent immediate hazards to subjects using the Modification/Update Form. Modifications requiring the prior review and approval of the IRB include but are not limited to: changing the protocol or study procedures, changing investigators or funding sources, changing the Informed Consent Document, increasing the anticipated total number of subjects from what was originally approved, or adding any new materials (e.g., letters to subjects, ads, questionnaires).

Unanticipated Problems Involving Risks: You must promptly report to the IRB any unexpected adverse experience, as defined in the IRB/HRPO policies and procedures, and any other unanticipated problems involving risks to subjects or others. The Reportable Events Form (REF) should be used for reporting to the IRB.

Audits/Record-Keeping: Your research records may be audited at any time during or after the implementation of your project. Federal and University policies require that all research records be maintained for a period of seven (7) years following the close of the research project. For research that involves drugs or devices seeking FDA approval, the research records must be kept for a period of three years after the FDA has taken final action on the marketing application, if that is longer than seven years.

Additional Information: Complete information regarding research involving human subjects at Washington University is available in the "Washington University Institutional Review Board Policies and Procedures." Research investigators are expected to comply with these policies and procedures, and to be familiar with the University's Federalwide Assurance, the Belmont Report, 45CFR46, and other applicable regulations prior to conducting the research. This document and other important information is available on the HRPO website http://hrpo.wustl.edu/.